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ECOLOGY
State of Washington

Quality Assurance Monitoring Plan

Puget Sound Temperature, Salinity, *In Situ* Fluorescence, Turbidity, and Colored Dissolved Organic Matter Marine Water Monitoring using the *Victoria Clipper IV* Ferry Vessel

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Author and Contact Information

Suzan Pool, Christopher Krembs, and Julia Bos
P.O. Box 47600
Environmental Assessment Program
Washington State Department of Ecology
Olympia, WA 98504-7710

Communications Consultant: phone 360-407-6834.

Washington State Department of Ecology - www.ecy.wa.gov

- Headquarters, Olympia 360-407-6000
- Northwest Regional Office, Bellevue 425-649-7000
- Southwest Regional Office, Olympia 360-407-6300
- Central Regional Office, Yakima 509-575-2490
- Eastern Regional Office, Spokane 509-329-3400

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Approved by:

Signature:	Date: June 2015
Suzan Pool, Author / Co-Principal Investigator, EAP	
Signature:	Date: June 2015
Christopher Krembs, Author / Project Manager, EAP	
Signature	Date: June 2015
Julia Bos, Author / Co-Principal Investigator, EAP	
Signature:	Date: June 2015
Carol Maloy, Authors' Unit Supervisor, EAP	
Signature:	Date: June 2015
Jessica Archer, Authors' Section Manager, EAP	
Signature:	Date: June 2015
Joel Bird, Director, Manchester Environmental Laboratory	
Signature:	Date: June 2015
Bill Kammin, Ecology Quality Assurance Officer	

Signatures are not available on the Internet version.
EAP: Environmental Assessment Program

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2.0 Abstract

Washington State Department of Ecology (Ecology) is using ferry vessels as a cost-effective means of data collection. En route ferry-based monitoring is valuable because it can capture near-surface events such as blooms, river input, and tidal exchange on a daily basis and over a large geographic area. Ferry-based monitoring between Seattle, WA, USA and Victoria, B.C., Canada enables Ecology to collect representative daily water quality data along an approximately 80-mile transect. The temporal and spatial scale and resolution of ferry-based monitoring lend itself to:

- Acquire detailed information on near-surface variability, patterns, and gradients of physical and bio-optical water quality variables (temperature, salinity, fluorescence, turbidity, and colored dissolved organic matter).
- Collect spatially representative monitoring data at very low cost.
- Infer processes of water exchange across Admiralty Reach at surface and depth in response to tidal and weather forcing.
- Leverage and expand on existing remote sensing efforts that are compromised by cloud cover and lack of ground truthing information.
- Alleviate technical challenges with instruments being fully submerged under water (pressure effects and biofouling).

For proper sensor performance and data transmission, servicing, equipment maintenance, calibration, and sensor and equipment performance, routines are outlined to ensure highest data quality, completeness, and integrity over time. While these latter variables are in Ecology's control, vessel issues and weather conditions may change ferry routes and departure/arrival times, and thus, produce data gaps. *Victoria Clipper IV* ferry monitoring support is based on a volunteer-based collaboration and does not require Clipper Navigation, Inc. to maintain Ecology's ferry sensors on their vessels.

3.0 Background

Ecology and Clipper Navigation, Inc. started a partnership in 2009 to conduct a cost-effective pilot project. The collaboration tests the proof of concept that Ecology could collect time-series data along surface gradients of physical and bio-optical variables. The resulting data will be relevant to describe patterns and extent of water quality in context of climatic, tidal, and biological influences. Specifically, Ecology has two oceanographic sensor packages synchronized in time and space using a global positioning system (GPS) on the *Victoria Clipper IV* ferry vessel. The instruments are being used to measure surface water properties and spatial gradients and to infer dynamics of water exchange across Admiralty Sill, which is located between Puget Sound and the Strait of Juan de Fuca.

Data from this project leverage existing satellite and remote sensing efforts by providing daily calibration and ground truthing information. Ferry data interpolate monthly data from our marine waters flight program, temporally and spatially, and provide context for continuous data from our *in situ* moorings. Results from the combination of data sets are expected to increase our understanding of the timing and spatial extent of surface blooms, patterns of sediment transport, and geographical extent of freshwater influences.

At the Triple Junction in Central Sound (salt water area between southern tip of Whidbey Island, northern Kitsap Peninsula, and Edmonds) and the Strait of Juan de Fuca, major freshwater inputs converge and carry sediments from Skagit, Stillaguamish, Snohomish, and Fraser Rivers. The geographical boundary of surface water masses is strongly dependent on water flows, wind speed and direction, and tidal forcing functions. River influence on spatial gradients, variability, dynamic of water masses, character of vertical stratification relevant to mixing and biological activity, and dissipation of pollutants is indisputable. Data collected aboard the *Victoria Clipper IV* are, therefore, an integral and important asset to refine existing hydrodynamical and future water quality models in this region. The *Victoria Clipper IV* ferry-based monitoring activity is a complementary effort to Canadian ferry-based monitoring in Georgia Basin.

3.1 Study area and surroundings

The study area is the marine water body of greater Puget Sound and the Strait of Juan de Fuca and focuses on the routes taken by the *Victoria Clipper IV* ferry vessel. The ferry routes run between Seattle, WA, USA and Victoria, B.C., Canada twice daily (Figure 1). Typically, the vessel transits through Puget Sound across Elliot Bay, along the west side of Whidbey Island, and across Admiralty Sill, and then transits through the Strait of Juan de Fuca. The normal vessel transect is 81 mi (130 km) in length. The vessel speed can reach 30 mph. On the normal route, there are population centers on shore, including Seattle, Bremerton, Everett, Port Townsend, and Victoria, B.C. Freshwater influences stem from the convergence of Skagit, Stillaguamish, Snohomish, Duwamish, and Fraser Rivers. Stratified surface water from Hood Canal carries freshwater from the Skokomish River into Admiralty Inlet. This surface water mass has distinct bio-optical signatures. Commercial and recreational vessels transit in and around Puget Sound and the Strait through major navigation channels. Large and persistent tidal fronts, regions of strong vertical water mixing, and large *Noctiluca* blooms with significant influences on phytoplankton biomass occur along *Victoria Clipper IV*'s transect.

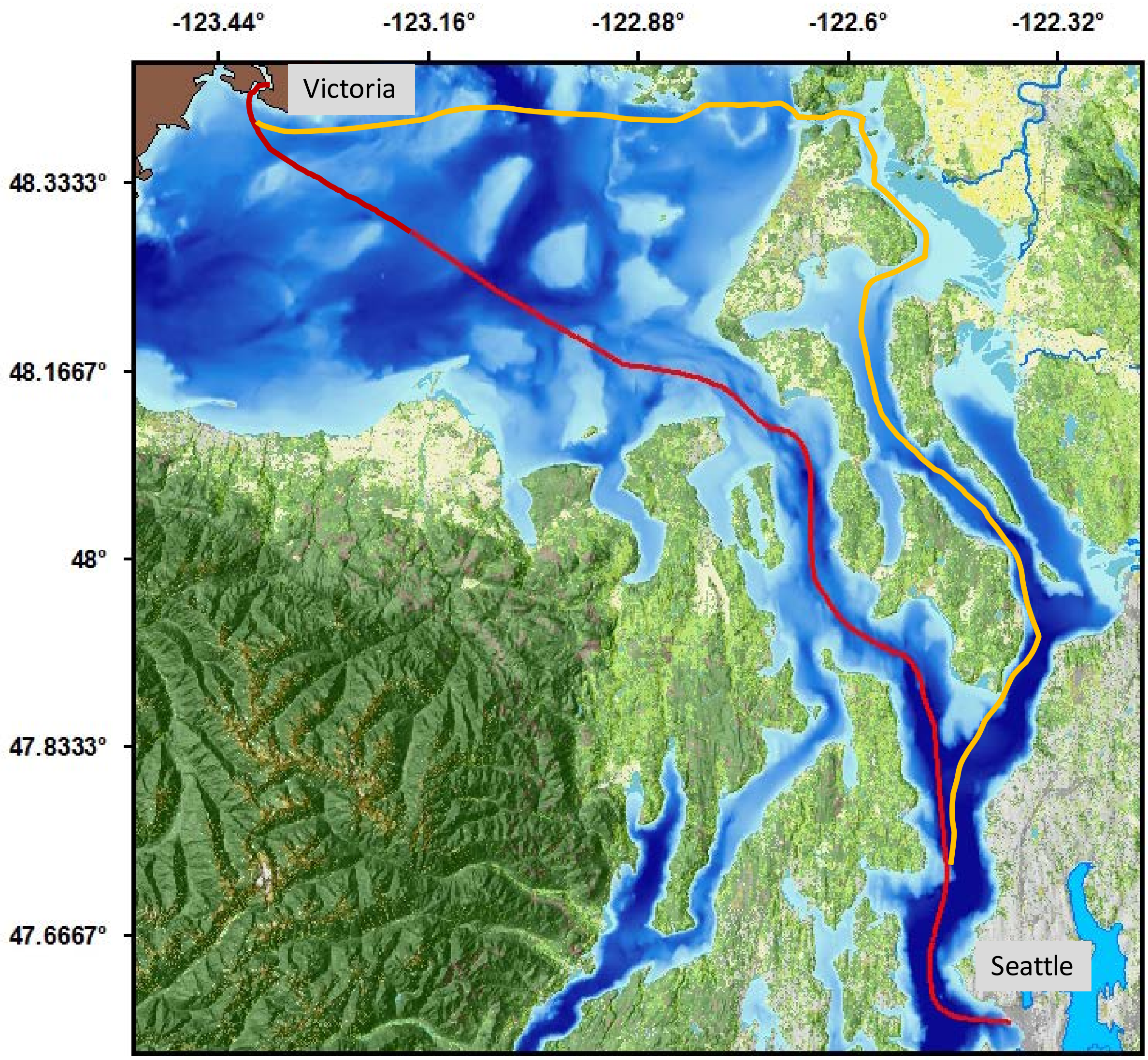

Figure 1. Study area showing the primary and daily ferry travel route between Seattle, WA, USA and Victoria, B.C., Canada (red line).

Alternative route used during unfavorable weather and water conditions is also shown (yellow line).

3.1.1 Logistical problems

Two of Ecology's monitoring sensors are located inside the *Victoria Clipper IV* vessel. Servicing the sensors require that Ecology staff coordinate with Clipper Navigation, Inc. on a day the vessel is docked in Seattle to gain access to the vessel. Typically, the vessel is docked one to two days per week. During summer or holidays when ferry passenger loads are high, the vessel is expected to sail daily. The day the vessel is docked at its home port is usually not determined until the day before or in the morning, posing logistical challenges to the sensor maintenance and calibrations. Logistical problems include scheduling conflicts, staff availability, and vessel availability.

One instrument is located in the vessel's sea chest which transports seawater into multiple water pipes. The sea chest needs to be opened to access the instrument for cleaning and calibrations. Before opening the sea chest, valves around it must be closed. Thus, Clipper Navigation, Inc. provides assistance in ensuring that valves between the vessel's sea chest and multiple water pipes are closed before servicing the instrument

Annually, the *Victoria Clipper IV* is dry-docked for routine maintenance. Unexpected repairs result in additional dock time at its home port or a shipyard, but such events are infrequent.

The data logging system is composed of electronic equipment. Each component of this system is exposed to fine oily dust and high heat (~100-120 °F) inside the engine room where instruments, electronics, and sensors are located. All components are subject to vessel movements. Surface water conditions are challenging to moving parts and thus, shorten instrument life expectancies. The extreme environmental conditions, exposure to salt in ambient air, and use of degreasers in the engine room tend to affect and degrade electronic cable insulations over time. Therefore, it is critical to ensure that electronics are protected from oily dust, solvents, and temperature spikes when fans are turned off. Rugged components, detailed attention to equipment condition, and good maintenance are therefore equally important as with moored sensors.

3.1.2 History of study area

Ecology has conducted marine waters monitoring in Puget Sound since 1967. Starting in 1973, the monitoring was standardized into monthly sampling of core and rotating stations using a float plane. The monthly marine flights focus on vertical distribution of water quality properties from surface to depth. In late 2005, *in situ* moorings were installed at strategically located sites. In 2010, aerial photography was added to examine optical water quality, biological responses to nutrients, and near-surface spatial structure and processes. Examining the historical and present context of water dynamics in Puget Sound prompted a need for cost-effective, but more spatially and temporally representative, sampling alternatives. Therefore, Ecology started using a ferry vessel to focus on the productive marine water surface that could be used to integrate over multiple scales and leverage marine flight data.

3.1.3 Parameters of interest

When measuring the surface marine waters with instruments, parameters of interest are:

- Water temperature – Indicator of temporal and spatial changes in surface water temperature.
- Salinity – Indicator of ocean and freshwater exchanges.
- *In situ* chlorophyll fluorescence – A proxy of algal biomass to determine temporal and spatial extent of surface blooms.
- Turbidity – Indicator of suspended sediment from rivers, tidal re-suspension, shore erosion, and dredging.
- Colored dissolved organic matter (CDOM) – Indicator of freshwater influences from rivers carrying specific optical signatures.

En route ferry data, along with Canadian ferry data, support remote sensing ground truthing efforts in the region. These rely on daily ground truthing information of:

- Water color – True color; red, green, blue (RGB) composites.
- Water clarity – Turbidity.
- Algal biomass – Chlorophyll *a* and/or *in situ* fluorescence.
- Freshwater influence from different sources (humic substances) – CDOM.
- Sea surface temperature.

3.1.4 Results of previous studies

Historical and existing monitoring data indicate gaps in understanding fine-scale spatial and temporal pattern and processes of surface water dynamics within Puget Sound. In the productive upper water column, such water processes affect optical, chemical, and physical properties and, indirectly, marine life in Puget Sound. Previous investigations of the study area illustrated that, on interannual time scales, phytoplankton biomass has declined in the second half of the summer, nitrate and phosphate concentrations have been increasing, and microzooplankton grazing by bright orange protist *Noctiluca* can be extensive. These protists are observable from the air and measured by ferry data in Central Sound as well as the Juan de Fuca and Georgia Straits. Recent aerial observations have documented the enormous spatial heterogeneity of water properties, sediment loads, and biological responses (e.g., dinoflagellate blooms and jellyfish accumulations) in late summer. The geographical extent and dynamic of surface water isotherms across Admiralty Reach have revealed that event-driven water exchange between Puget Sound and the Straits occur on a large scale. The combination of observations by the long-term marine monitoring group can be found in the following reports:

- PSEMP Marine Waters Workgroup. 2014. Puget Sound marine waters: 2013 overview. S.K. Moore, K. Stark, J. Bos, P. Williams, J. Newton, and K. Dzinbal (Eds). http://www.psp.wa.gov/downloads/psemp/PSmarinewaters_2013_overview.pdf
- PSEMP Marine Waters Workgroup. 2013. Puget Sound marine waters: 2012 overview. S.K. Moore, K. Stark, J. Bos, P. Williams, J. Newton, and K. Dzinbal (Eds). http://www.psp.wa.gov/downloads/psemp/PSmarinewaters_2012_overview.pdf

- PSEMP Marine Waters Workgroup, 2012. Puget Sound marine waters: 2011 overview. S.K. Moore, R. Runcie, K. Stark, J. Newton, and K. Dzinbal (Eds). http://www.psp.wa.gov/downloads/psemp/PSmarinewaters_2011_overview.pdf
- Krembs C., 2013. Eutrophication in Puget Sound. In: Irvine, J.R. and Crawford, W.R., 2013. State of physical, biological, and selected fishery resources of Pacific Canadian marine ecosystems in 2012. DFO Can. Sci. Advis. Sec. Res. Doc. 2013/032. pp. 106-112. http://www.dfo-mpo.gc.ca/Csas-sccs/publications/resdocs-docrech/2013/2013_032-eng.pdf
- Krembs C. 2012. POSTER: Eyes Over Puget Sound: Integrating Multiple Observations to Report Current Conditions of Water Quality in Puget Sound and the Strait of Juan de Fuca https://fortress.wa.gov/ecy/publications/summarypages/1203034.html

3.1.5 Regulatory criteria or standards

Results will contribute to decisions on marine water quality assessment 303(d) listing of the federal Clean Water Act.

4.0 Project Description

To better understand and predict marine water quality throughout Puget Sound, Ecology has sought innovative, cost-effective, and more economical approaches to collecting marine water monitoring data. Use of research vessels to collect daily marine water quality data can be expensive and is typically not available year-round. Collaboration with Clipper Navigation, Inc. provides us with a cost-saving approach to collect data that are more representative of surface water processes within Puget Sound and the Straits. Therefore, we are focusing on an extremely important, yet under-sampled, aspect of surface water quality with desirable temporal and spatial resolution across a large geographical area.

The project is based on deployment of oceanographic sensors and a GPS with two different resolutions. The instruments will collect data every five seconds. This frequency will generate data on a 100-m spatial resolution and a 4-hr temporal resolution. The resulting data sets are necessary to provide ground truthing information to calibrate available remote sensing images and quantify the exchange of water masses. They will also support management decisions for marine water quality and improve the performance of numerical and harmful algal bloom (HAB) prediction models in Puget Sound.

4.1 Project goals

The goals of this project are to:

- Increase understanding of spatial gradients, variability, and dynamic of water masses, river plumes, algal blooms, and suspended sediments, particularly around Admiralty Reach.
- Understand the influence of Fraser River intrusions into Puget Sound in context of wind and tidal constituents in summer.

- Understand the dynamic of bottom ocean water intrusions and surface water compensatory export across Admiralty Reach, a process that can be monitored by the location and excursions of warmer isotherms that originate in Puget Sound and extend into the colder surface waters of the Straits in summer.
- Understand and spatially predict patterns of water quality throughout Puget Sound.
- Gain knowledge on event-driven marine and fresh water exchange through Admiralty Reach (e.g., storms, anomalies in precipitation, and river flows).
- Improve our water quality assessment decisions for the 303(d) listings under the Clean Water Act.
- Improve the performance of numerical models in Puget Sound.
- Understand the scale of impact and dynamic of *Noctiluca* blooms on phytoplankton biomass.

4.2 Project objectives

Objectives of the study are to:

- Collect continuous, high quality data of surface waters from ferry vessel transits between Seattle and Victoria, B.C.
- Provide detailed daily ground truthing information for satellite images of water temperature, sediment and algal concentrations.
- Extend and interpolate data of monthly marine flight program and *in situ* moorings and examine their temporal and spatial patterns.
- Analyze temporal and spatial variability of water masses, particularly in Admiralty Reach in context of tidal constituents, freshwater budgets, and weather influences.

4.3 Information needed and sources

One aspect of analyzing data from the oceanographic instruments on the *Victoria Clipper IV* ferry vessel is to combine data with remote sensing information. These data will provide daily ground truthing information for calibration of remote sensing information. Likewise, changes in water conditions can be seen in ferry data when cloud cover excludes satellite images. Over time, spatially explicit baselines of patterns and gradients can be formulated that instruct and refine existing modeling efforts for water quality HAB predictions, sediment transport, and oil spill risk assessments.

Additional information and sources that may be needed for examining data collected on the ferry include, but are not limited to, ocean and climate data and river flow data from external agencies. The U.S. Geological Survey, University of Washington, and the National Oceanic and Atmospheric Administration are some of the agencies that provide such data on the internet or through specific requests. The external data will be used to provide an overall context of potential physical forces on water dynamics and conditions observed in the ferry data.

4.4 Target population

This study does not target a specific population. The water dynamics and processes have potential effects for all marine species within greater Puget Sound.

4.5 Study boundaries

The study boundary surrounds the ferry vessel traveling routes. The most frequent route runs from Seattle, WA to Victoria, B.C. by way of Admiralty Inlet. In case of poor weather, Clipper Navigation, Inc. may choose to travel along the east side of Whidbey Island instead of through Admiralty Inlet. The routes are shown in Figure 1.

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

WRIAs
- 2 – San Juan
- 3 – Lower Skagit/Samish
- 5 – Stillaguamish
- 6 – Island
- 7 – Snohomish
- 8 – Cedar/Sammamish
- 9 – Duwamish/Green
- 15 – Kitsap
- 17 – Quilcene/Snow

HUC numbers
- 17110003
- 17110019
- 17110020

4.6 Tasks required

The following tasks will be conducted for this project:

- Maintain and service sensors on a regular basis.
- Perform quality control checks of sensors using liquid standards, water samples, or a second sensor.
- Calibrate sensors according to manufacturer's recommendations.
- Monitor exposure of electronics to extreme conditions of the ferry vessel engine room.
- Confirm successful recording of sensor measurements and their subsequent remote data transmissions.
- Transfer data into designated database.

- Assess data to determine whether they meet quality objectives.
- Develop data products that can be readily understandable by the public.
- Analyze data, taking into consideration potential effects from sensor biofouling, climate and ocean conditions, river flows, tidal effects, primary productivity, water mass movements, and other similar parameters.

4.7 Practical constraints

The practical constraints are few. The main constraint is access to the ferry vessel. Another constraint is exposure of the data logging system and other electronic equipment to fine oily dust, high air temperature spikes, power supply in port, degreaser in the engine room, and rough seas. There is potential constraint on software needs for data processing, repository, and analysis. Initial test periods have shown that these obstacles can be successfully overcome with appropriate planning, equipment, and communication with the vessel staff.

Data collection and assessment may be cancelled or curtailed when budget constraints result in staff reductions or limited availability of resources and when equipment fails to generate data that meet quality standards. Resources include equipment and supplies, calibration services, and analytical laboratory and information management services.

4.8 Systematic planning process

This QAMP is the culmination of the systematic planning process for the project.

5.0 Organization and Schedule

5.1 Key individuals and their responsibilities

Table 1 lists staff who will be involved with the project and QAMP along with their responsibilities. All project staff are employees of the Washington State Department of Ecology.

Table 1. Organization of project staff and responsibilities.

Staff (all are EAP)	Title	Responsibilities
Christopher Krembs Marine Monitoring Unit WOS Phone: 360-407-6675	Project Manager	Co-authors the QAMP. Conducts QA review of data, analyzes and interprets data. Writes report sections and final report on ferry data.
Julia Bos Marine Monitoring Unit WOS Phone: 360-407-6674	Co-Principal Investigator	Co-authors QAMP. Oversees and reports on field sampling, sensor performance tests during deployment, and transportation of samples to the laboratory. Conducts QA review of data, analyzes, and interprets calibration data, and assigns data quality flags. Assists project manager with project duties as needed.
Suzan S. Pool Marine Monitoring Unit WOS Phone: 360-407-7287	Co-Principal Investigator	Co-authors QAMP. Collects field and sensor calibration data. Maintain data logging system and track instrument and maintenance routines. Assists project manager with project duties as needed.
Carol Maloy Marine Monitoring Unit WOS Phone: 360-407-6742	Unit Supervisor for the Project Manager	Provides internal review of the QAMP, approves the budget, and approves the final QAMP.
Jessica Archer WOS Phone: 360-407-6596	Section Manager for the Project Manager	Reviews the project scope and budget, tracks progress, reviews the draft QAMP, and approves the final QAMP.
Joel Bird Manchester Environmental Laboratory Phone: 360-871-8801	Director	Reviews and approves the final QAMP.
William R. Kammin Phone: 360-407-6964	Ecology Quality Assurance Officer	Reviews and approves the draft QAMP and the final QAMP.

EAP: Environmental Assessment Program
QAMP: Quality Assurance Monitoring Plan
WOS: Western Operations Section

5.2 Special training and certifications

All personnel who conduct field activities will receive training on data loggers, electronic components, sensor operation and calibration, GPS, liquid standard and sample handling, program QA/QC, and safety. Each staff person is required to be familiar with this QAMP 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 on this project will also be familiar with data management and analysis procedures.

Personnel who service the sensors on board the *Victoria Clipper IV* may be required to obtain a Transportation Worker Identification Credential card for security access to the dock and vessel. This card can be obtained from the U.S. Department of Homeland Security, Transportation Security Administration. In addition, occasional work on the vessel may require travel to Victoria, B.C. For this, personnel must have a U.S. Passport or a Washington Enhanced Driver License.

5.3 Organization chart

See Table 1.

5.4 Project schedule

Maintenance work on board the ship is expected to occur every six weeks to service the bio-optical sensors and check other instruments and electronics. This frequency is necessary to control biofouling that may occur on the optical surfaces of sensors and accumulation of flotsam in a strainer basket inside the ferry vessel's sea chest. During routine field servicing, the Turner Designs C3 optical sensor package will be calibrated and cleaned and water samples will be collected. Data will be remotely transferred once daily from a data logging system on board the ferry vessel to a cloud-computing provider's server. Data will then be processed and analyzed at Ecology's headquarters. Data reviews and applying QC codes will occur monthly. Table 2 shows the proposed project schedule for completing field and laboratory work, data review and quality assurance, and reports.

Table 2. Proposed schedule for completing field and laboratory work, data review, and reports.

Field and laboratory work	Due date	Lead staff
Field work completed	Every six weeks	Suzan Pool
Laboratory analyses completed	1 month post-collection	Suzan Pool
Data receipt and processing		
Instrument and sensor data receipt confirmed	Daily	Suzan Pool
Data streams synchronized and processed	Every two weeks	Julia Bos
Laboratory data processed	1 month post-analyses	Suzan Pool
Data review and quality assurance		
Instrument and sensor data review completed	Once a month	Julia Bos
Laboratory data review completed	1 month post-analyses	Julia Bos
Final report		
Author lead / Support staff	Christopher Krembs / Julia Bos / Suzan Pool	
Schedule		
Draft due to supervisor	3 months after sampling year is complete	
Final (all reviews done) due to publications coordinator	4 months after sampling year is complete	
Final report due on web	4 months after sampling year is complete	

In addition, staff will report on recent data in the monthly Eyes Over Puget Sound (EOPS) summaries, posted on the Ecology website.

5.5 Limitations on schedule

The schedule is constrained by the availability of Suzan Pool's project position.

5.6 Budget and funding

Budget estimates are separated into three categories: (1) Maintenance of data logging system and remote data transmission, (2) Laboratory analysis of water samples, and (3) Setting up the framework for data management and products. Estimates do not include existing equipment and supplies previously obtained for this and other projects.

The extreme conditions of the engine room of the ferry vessel expedite normal wear and tear on electronics such as data loggers; therefore, funds are needed to replace worn electronics. Data are transmitted to a cloud-computing provider on a daily basis for a fee. Estimates for maintaining functional electronics and remote data transmissions are listed in Table 3.

Table 3. Project budget estimates for maintaining data logging system and remote data transmission for the 2015 fiscal year ending on June 30, 2015.

The subtotals for cellular phone account and cloud-computing account are not given because this is a monthly cost expected to remain past June 2015.

Item	Quantity	Cost Per Item	Subtotal
Data Logging System			
Spare data logger	1	$470.00	$470.00
Spare SD cards with Wi-Fi capability and 32 GB storage	3	$179.97	$539.91
Spare SD to CF Type II card adapter	1	$44.97	$44.97
Remote Data Transmission			
Cellular modem with 4G network capability	1	To be determined	To be determined
Cellular phone account	1	$40.00/month	n/a
Cloud-computing account	1	$20.00/month	n/a
Sensors			
Thermosalinograph	1	$6,050.00	$6,050.00
Sea chest cover for second fluorometer	1	$2,521.00	$2,521.00
		Subtotal	$9,625.88

Water samples for *in vitro* chlorophyll *a* concentrations will be analyzed by staff in the Marine Laboratory at Ecology's Operations Center. Calibrations of the on-board fluorometer require using liquid standards which need to be replenished regularly. Budget estimates for these are in Table 4.

Table 4. Annual budget estimates for sensor calibrations, water samples analysis, and reagents.

Parameter / Reagent / Supply	Number of Samples	Number of QA Samples	Total Number of Samples	Quantity	Cost Per Item	Subtotal
Calibration of Sensors						
Thermosalinograph	n/a	n/a	n/a	1	$1,850.00	$1,850.00
Liquid standard for CDOM	9	0	9	5 x 1 L	$95.00	$475.00
Liquid standard for turbidity	9	0	9	1 x 3.8 L	$320.10	$320.10
Analysis of Water Samples						
Chlorophyll *a* analysis	27	9	36	n/a	$0	$0
Glass fiber filters (25- and 27-mm)	27	9	36	1 box each filter size	$269.77	$269.77
Acetone, HPLC grade	27	9	36	4 L	$190.38	$190.38
					Subtotal	$3,105.25

One funding source is a grant from the Northwest Association of Networked Ocean Observing System (NANOOS). Efforts will be made to stay within budget; however, costs may be higher than initial quotes or estimates by the time of expenditures because of cost inflation and unforeseen circumstances such as equipment repairs.

6.0 Quality Objectives

Quality objectives are statements of the precision, bias, and lower reporting limits necessary to meet project objectives. Precision and bias together express data accuracy. Other considerations of quality objectives include representativeness and completeness. Quality objectives apply equally to field and laboratory data collected by Ecology, to data collected by entities external to Ecology, and to other analysis methods used in this study.

6.1 Decision Quality Objectives (DQOs)

Not applicable.

6.2 Measurement Quality Objectives (MQOs)

Field sampling procedures and laboratory analyses inherently have associated uncertainty with results in data variability. Measurement quality objectives (MQOs) state the acceptable data variability for a project. *Precision* and *bias* are data quality criteria used to indicate conformance with MQOs. The term *accuracy* refers to the combined effects of precision and bias (Lombard and Kirchmer, 2004).

6.2.1 Targets for precision, bias, and sensitivity

6.2.1.1 Precision

Precision is a measure of the variability in the results of replicate measurements due to random error. Random error is imparted by the variation in concentrations of samples from the environment as well as other introduced sources of variation (e.g., field and laboratory procedures). The ferry monitoring project will collect data from field instruments and laboratory analyses. Precision is assessed by conducting performance checks and calibrations of field instruments and by collecting three replicate water samples for chlorophyll *a* concentrations during each servicing. Table 5 lists acceptable MQOs for all parameters that will be collected during this project and will be used to identify whether a datum is acceptable and meets data quality criteria.

Table 5. Measurement Quality Objectives of parameters to be collected during field servicing and laboratory analyses.

Parameter	Method	Replicate Samples (Precision)	Lowest Concentrations of Interest (Sensitivity)
		Relative Standard Deviation (RSD)	Units of Concentration
Field Measurements			
In situ Chlorophyll Fluorescence	Turner Designs C3 Submersible Fluorometer	n/a	0.025 ug/l
Turbidity	Turner Designs C3 Submersible Fluorometer	n/a	0.05 NTU
CDOM	Turner Designs C3 Submersible Fluorometer	n/a	0.5 ppb
Temperature	Turner Designs C3 Submersible Fluorometer	n/a	-2 °C
Temperature	Teledyne RDI Citadel TS-NH Thermosalinograph	n/a	-5 °C
Conductivity	Teledyne RDI Citadel TS-NH Thermosalinograph	n/a	0 mS/cm
Global Position Coordinates	Garmin GPS 17x HVS	n/a	n/a
Laboratory Analyses			
In Vitro Chlorophyll *a* Extract	EPA 445.0 [1]	10% [2]	0.01 ug/l [2]

[1] Majority of methods follow EPA 445.0 (Arar and Collins, 1997) with slight modifications to follow protocols recommended by Puget Sound Estuary Program (1991).
[2] Puget Sound Estuary Program (1991); we rounded precision up from ±8% to 10%.

6.2.1.2 Bias

Bias is the difference between the population mean and the true value of the parameter being measured. Bias in field measurements and samples will be minimized by strictly following standard operating procedures for each parameter being measured. In addition, bias is usually addressed by calibrating field and laboratory instruments and by analyzing lab control samples (e.g., blanks for chlorophyll *a* samples). For this project, bias of field measurements will be reduced by cleaning and calibrating field instruments on a regular basis.

6.2.1.3 Sensitivity

Sensitivity is a measure of the capability of a method to detect a substance. It is commonly described as a detection limit. In a regulatory sense, the method detection limit (MDL) is usually used to describe sensitivity. Field and laboratory sensitivity of each parameter is listed in Table 5.

6.2.2 Targets for comparability, representativeness, and completeness

6.2.2.1 Comparability

For comparability with other projects in the same study area, standard operating procedures (SOPs) and recommended manufacturer procedures for sensors will be followed. The Ecology SOPs are:

- EAP025 *Standard Operating Procedure for Seawater Sampling, version 2.0* (Bos, 2013)
- EAP026 *Standard Operating Procedure for Chlorophyll* a *Analysis, version 3* (Bos, 2012)

Operations, maintenance, and calibrations of sensors will follow recommendations given in user manuals:

- Turner Designs C3 Submersible Fluorometer User's Manual, Revision L, http://www.turnerdesigns.com/t2/doc/manuals/998-2300.pdf
- Teledyne RD Instruments Citadel TS-NH Thermosalinograph Technical Manual, available on the manufacturer's website after setting up a personal account to access the "Documentation" section: http://www.rdinstruments.com/Default.aspx
- Garmin GPS 17x HVS manuals: http://support.garmin.com/support/manuals/manuals.htm?partNo=010-00694-00&language=en&country=US

Following these standardized procedures supports comparability of data between projects conducted within Ecology and by others outside of Ecology.

6.2.2.2 Representativeness

The *Victoria Clipper IV* transits between Seattle, WA and Victoria, B.C. The regular ferry route crosses over the Admiralty Sill between Port Townsend, WA and Kingston, WA. Admiralty Reach is considered a site of major water exchanges between the Strait of Juan de Fuca and Puget Sound. Therefore, collecting data on surface waters from Seattle through the Central Basin in Puget Sound, and across Admiralty Reach and the Strait is the most representative sample available for the sampling area.

The alternate ferry route is traveled infrequently and during times of questionable and unsatisfactory weather conditions. This route runs from Seattle to the east side of Whidbey Island and then across the Strait of Juan de Fuca to Victoria, BC. While this route does not cross the Admiralty Sill, measuring surface waters in another part of Puget Sound enhances the representativeness of the sampling area.

Measurements are made at 5-sec intervals between 6:15 a.m. and 10:00 p.m. Pacific Standard Time (PST) daily. This high frequency contributes to the representativeness of spatial and temporal variability of water dynamics, algal blooms, river influences, and fine-scale water exchanges within Puget Sound. Though we take steps to assure representativeness, data users must be careful not to overstate these measurements.

6.2.2.3 Completeness

EPA has defined completeness as a measure of the amount of valid data needed to be obtained from a measurement system (Lombard and Kirchmer, 2004). The goal for this study is to collect and analyze 100% of data measurements collected by all three instruments on board the ferry vessel. However, this may not be possible for a few reasons:

- An instrument needs repairs.
- Bio-fouling of instruments affects water measurements.
- Exposure of data logging equipment to heat, oil, and dust stalls or stops recording of data.

Therefore, a completeness objective of 95% is acceptable. To minimize the risk of unexpected data loss, we will conduct routine servicing of sensors and monitor data remotely for indications of malfunctioning equipment.

7.0 Sampling Process Design (Experimental Design)

7.1 Study design

The study design is limited to where and when the ferry vessel travels (Figure 1). The sensors and GPS on board the vessel are configured to produce data records with high temporal and spatial resolution. At this time, Ecology chooses to use an optical fluorometer, thermosalinograph, and GPS to collect measurements. All field measurements will come from surface waters along the ferry transit routes.

7.1.1 Field measurements

Ecology will deploy a Turner Designs C3 submersible fluorometer, Teledyne RDI Citadel TS-NH thermosalinograph, and a Garmin GPS 17x HVS. Selection of equipment does not imply any endorsements by Ecology. Each electronic device will take measurements from 6:15 a.m. to 10:00 p.m. PST daily with flexibility to adjust the start and end times as needed. The time range is controlled via a relay switchboard that has the capability for users to assign when one or more electrical items are turned on or off. Currently, Ecology is using the switchboard to control power to the three electronic sensors and their assigned serial data loggers (Figure 2). The sensors measure data every five seconds. Data are transmitted from the sensors to data loggers that record the data onto storage memory cards. Every 24 hours, the data are then telemetered to a cloud-computing server.

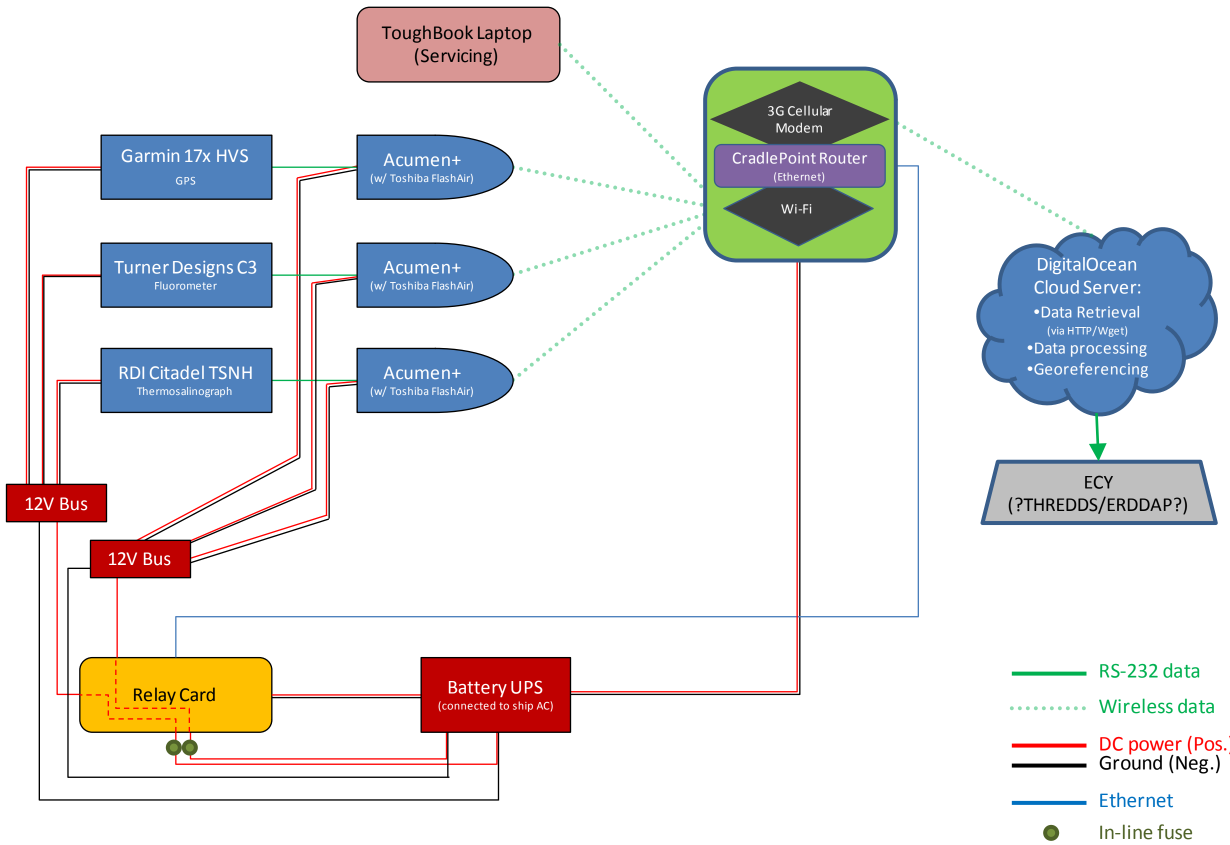

Figure 2. Wiring diagram of data logging system.

The optical fluorometer will be located on top of the vessel's sea chest in the engine room by using a modified sea chest cover specifically manufactured to make a watertight fit for the sensor and vessel. The fluorometer will have three optical lenses submerged in the water. Table 6 lists the optical lenses' detection and excitation characteristics.

Table 6. Application and characteristics of each optical lens in the fluorometer.

Application	LED (CWL; nm)	Excitation (nm)	Emission (nm)
In situ chlorophyll fluorescence	460	465/170	696/44
Turbidity	850	850	850
Colored dissolved organic matter	365	325/120	470/60

Water is passed through the vessel's hull and into the sea chest and before it continues into five pipes for the vessel engines, bilge, and other mechanical components (Figure 3).

The thermosalinograph is located in the stern of the vessel where it receives water from a water intake port near the top of the vessel's rudder. This sensor allows for water to flow through it on the way to its destination within the engine room (Figure 3).

The GPS is located on the aft of the passenger deck of the vessel and mounted to ensure an unobstructed view to the sky (Figure 3).

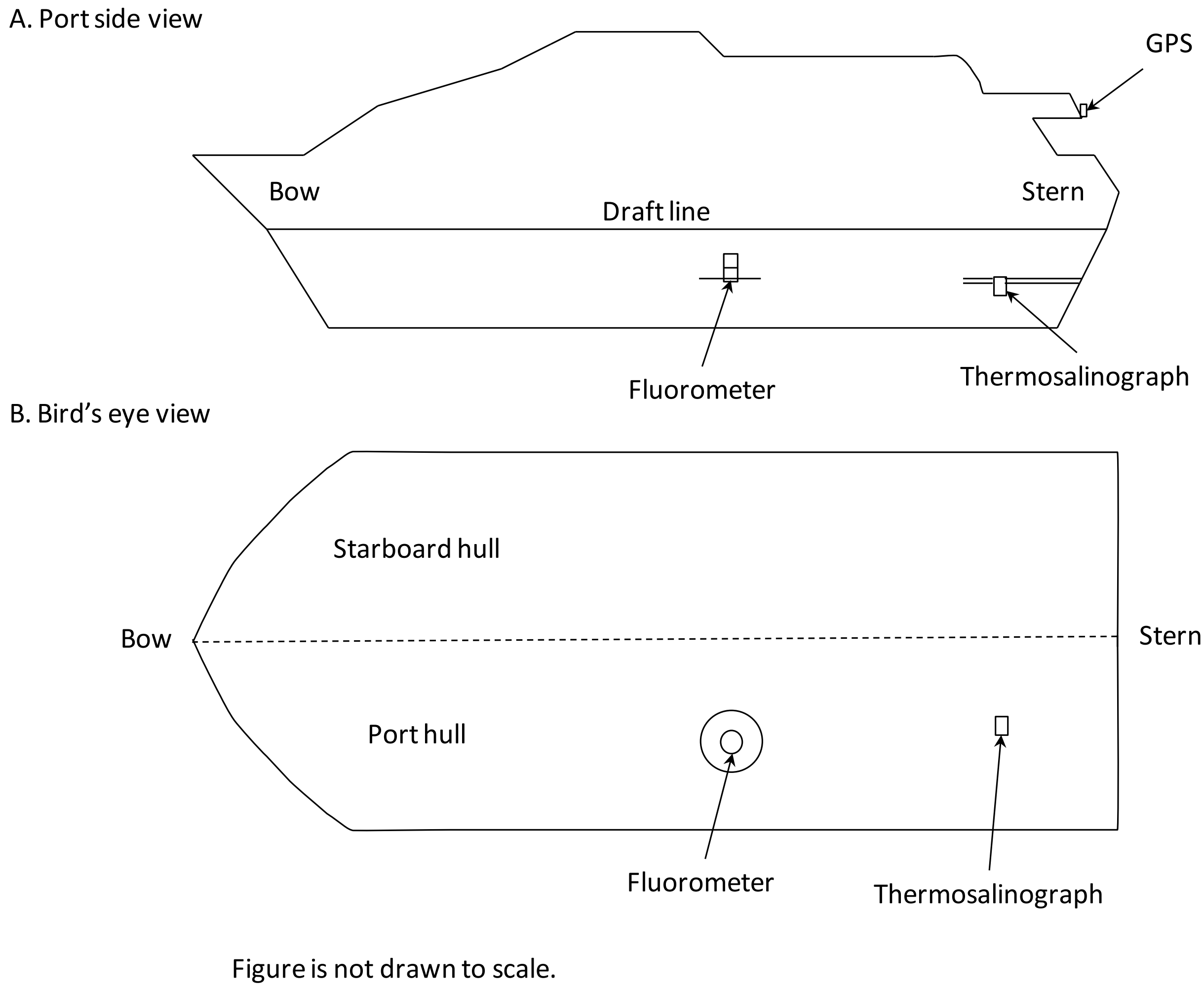

Figure 3. Diagrams show location of optical fluorometer, thermosalinograph, and GPS on the *Victoria Clipper IV*. A. Port side view shows approximate location of all three sensors. B. Bird's eye view shows approximate location of fluorometer and thermosalinograph in the port engine room.

During instrument maintenance, water samples for chlorophyll *a* analysis will be collected and analyzed to verify satisfactory sensor performance of the optical fluorometer as well as be used to calibrate the resulting chlorophyll fluorescence data. The chlorophyll samples will be analyzed at Ecology's Marine Laboratory.

7.1.2 Sampling location and frequency

Sampling will be along the *Victoria Clipper IV* ferry's regular route and rarely along the alternate route as shown in Figure 1. Water measurements and geospatial coordinates will be collected every five seconds between 6:15 a.m. and 10:00 p.m. PST daily.

7.1.3 Parameters to be determined

The parameters to be determined are listed in Table 5.

7.2 Maps or diagram

The study area and ferry routes are shown in Figure 1.

7.3 Assumptions of underlying design

An assumption is that the sampling instruments are functioning properly during deployments and that the data logging system is continuously recording data from all instruments simultaneously and accurately. A single transect cannot ascertain cross-channel or diurnal variability. This is especially the case for measurements taken when values change rapidly with the tide or the diurnal period.

7.4 Relation to objectives and site characteristics

Daily sampling of the entire ferry route supports the previously stated objectives of collecting continuous data, leveraging available satellite images, extending data to monthly flights and *in situ* moorings, and analyzing temporal and spatial variability of the waters within Puget Sound. Although, meeting these objectives are confined to the ferry routes and not a larger part of Puget Sound, the approach enables us to characterize and substantiate patterns of water movements and horizontal structure in greater Puget Sound and the Strait of Juan de Fuca.

7.5 Characteristics of existing data

During 2011 and 2012, the en route ferry data delivered new information on the importance of monitoring near-surface water processes in greater Puget Sound across large spatial gradients. Ecology collected preliminary *Victoria Clipper IV* data as a proof of concept starting in 2010 to understand the needs for instrument and electronic requirements. After a very successful test period of 2 years, computers and electronic circuits started to frequently malfunction. Simultaneously, we lost important staff to maintain the instrument and daily telemetry of the shipboard data. This resulted in a data set with increasing interruptions and issues. After breakthroughs in cabling and omitting ship-based computers, reliability of instruments has been dramatically restored and greatly improved. Existing data are currently being subjected to a QC procedure to apply quality labels which entails:

1. Range tests for sensors.
2. Data completeness and pattern tests.
3. Data review of multiple sensors in context over time.
4. Data review of multiple sensors in context over space.
5. Assignment of data quality labels.

As a result of the test period and having omitted technological issues that led to an overall improvement of the project, the new en route ferry monitoring now has QA/QC procedures and maintenance routines to ensure best data quality and transparent data quality assurance codes. Consequently, existing data will be examined to further understanding of the near-surface water processes in greater Puget Sound.

8.0 Sampling Procedures

8.1 Field measurement and field sampling SOPs

Field measurements will be taken along the entire ferry route, as long as sensors, GPS, and data logging system are fully functional. The optical fluorometer and thermosalinograph will be cleaned and calibrated in regular intervals following manufacturer's recommendations. At each servicing of the optical fluorometer, three water samples for chlorophyll *a* concentrations will be collected, filtered, and preserved following Ecology's SOP EAP025 (Bos, 2013) and EAP026 (Bos, 2012). Two minor differences from the SOPs are that (1) water will be collected with a clean polyethylene bottle, instead of with a Niskin grab sampler, from open water where reachable from the dock and (2) the glass microfiber filter will be stored in a plastic centrifuge tube instead of a glass centrifuge tube. Ecology's Marine Laboratory will analyze these samples following SOP EAP026 (Bos, 2012). Results from these water samples will be used to assess quality of data recorded by the optical fluorometer and to assure that the fluorometer is performing as expected.

8.2 Containers, preservation methods, holding times

Ecology will follow the SOPs for filtering and preserving marine water samples for determinations of chlorophyll *a* concentrations. Table 7 provides information on container, preservation method, and holding time for this sample parameter.

Table 7. Sample containers, preservation, and holding times.

Parameter	Matrix	Minimum Quantity Required	Container	Preservative	Holding Time
In Vitro Chlorophyll *a*	Water	125 mL	125 mL brown polyethylene bottle, filtered onto 25-mm GF/F filters, and transferred to 10 mL poly centrifuge tube	10 mL 90% acetone, and frozen to -20 to -70 °C	4 weeks

8.3 Invasive species evaluation

Field staff will follow Ecology's SOP EAP070 to minimize the spread of invasive species (Parsons et al., 2012). At this time, the study area is not an area of extreme concern. Regardless, staff will attempt to remove organisms and debris from equipment upon completion of field servicing and cleaning at the laboratory.

8.4 Equipment decontamination

Expectation that field gear will come in contact with high levels of contaminants is low and infrequent. Regardless, field staff will clean gear upon completion of servicing and again in the laboratory. If non-sensor field equipment may be contaminated, staff will follow Ecology's SOP EAP090 (Friese, 2014).

8.5 Sample ID

Sample identification (ID) is needed for the chlorophyll samples. Replicate water samples will be put into bottles that are labeled with unique ID numbers. Likewise, after samples are filtered, the filters will be placed in centrifuge tubes that are also labeled with unique ID numbers. From sampling to laboratory analysis, these bottle and tube numbers will be recorded on log sheets for field and laboratory use and thus linked to each field servicing.

8.6 Chain-of-custody, if required

As chlorophyll samples remain in Ecology's custody until they are analyzed in the Marine Laboratory, no chain-of-custody is required. Laboratory staff will be notified when chlorophyll samples are ready for analyses and the samples expire.

8.7 Field log requirements

Field log sheets will be used to record information during each field servicing. Information to be recorded is listed as follows:

- Date of field servicing
- Field technicians
- Instrument being serviced
- Time seawater was collected for chlorophyll *a* samples
- Chlorophyll bottle ID numbers
- Pre-cleaning measurements of the optical fluorometer, including times and ambient mediums used
- Post-cleaning measurements of the optical fluorometer, including times and ambient mediums, solid standards, and liquid standards used
- General servicing notes

8.8 Other activities

Any field staff new to working in the ferry vessel engine room and calibrating an optical fluorometer will be trained by senior field staff or the project manager. Relevant Ecology SOPs, the EAP Field Safety Manual, and field equipment manuals will be used as training materials.

After each field servicing, several tasks need to be completed when staff return to the laboratory. Data entries done in the field and finalized in the office will be reviewed to ensure completeness and accuracy. Sensor measurements of ambient water and standards will be reviewed to verify recent calibrations, obtain resulting medians, and compare with previous calibrations. This review step will ensure that sensors are performing as expected. Field servicing data will be transferred to an electronic database on a frequently archived network server.

9.0 Measurement Methods

9.1 Field procedures table/field analysis table

Field methods using sensors depend on the manufacturer's recommendation for deployment, maintenance, and calibration. The specifics of two sensors that Ecology deploys are listed in Table 8.

Table 8. Measurement methods (field and laboratory).

Analyte	Sample Matrix	Samples [Number/ Arrival Date]	Expected Range of Results	Method Detection Limit	Sample Prep Method	Analytical (Instrumental) Method
Field Methods						
In situ Chlorophyll Fluorescence	Water	11,340 per day	0 to 500 ug/l	0.025 ug/l	Blue light source	Turner Designs C3 Submersible Fluorometer
Turbidity	Water	11,340 per day	0 to 3000 NTU	0.05 NTU	Infrared light source	Turner Designs C3 Submersible Fluorometer
CDOM	Water	11,340 per day	0 to 5000 ppb	0.5 ppb	Ultraviolet light source	Turner Designs C3 Submersible Fluorometer
Temperature (Optical Fluorometer)	Water	11,340 per day	-2 to 50 °C	n/a	Probe	Turner Designs C3 Submersible Fluorometer
Temperature (Thermosalinograph)	Water	11,340 per day	-5 to 35 °C	n/a	Flow-through	Teledyne RDI Citadel TS-NH Thermosalinograph
Conductivity	Water	11,340 per day	0 to 70 mS/cm	n/a	Flow-through, non-external inductive field conductivity	Teledyne RDI Citadel TS-NH Thermosalinograph
Position Coordinates	Location	11,340 per day	47.5 to 48.5 °N, 122 to 124 °W	n/a	n/a	Garmin GPS 17x HVS
Laboratory Methods						
In Vitro Chlorophyll *a* Extract	Water	3 water samples every 6 weeks	0 to 250 ug/l	0.025 ug/l	EPA 445.0	Turner Designs 10-AU Fluorometer

9.2 Lab procedures table

The laboratory procedure for analyzing extracts of *in vitro* chlorophyll *a* samples is given in Table 8.

9.2.1 Analyte

The single analyte is the chlorophyll *a* pigment.

9.2.2 Matrix

The sampling matrix is seawater collected from where the *Victoria Clipper IV* ferry vessel is docked.

9.2.3 Number of samples

The number of chlorophyll *a* samples that Ecology expects to collect is three replicates every six weeks. This is also shown in Table 8.

9.2.4 Expected range of results

The expected range of results of chlorophyll *a* pigment extracts using a laboratory fluorometer is listed in Table 8.

9.2.5 Analytical method

The analytical method will follow SOP number EAP026 (Bos, 2012) and EPA method number 445.0 (Arar and Collins, 1997).

9.2.6 Sensitivity/Method Detection Limit (MDL)

The method detection limit is given in Table 8.

9.3 Sample preparation method(s)

Seawater samples collected for determinations of chlorophyll *a* concentrations are extracted using 90% HPLC-grade acetone. The extractions will follow procedures outlined in SOP EAP026 (Bos, 2012).

9.4 Special method requirements

Not applicable.

9.5 Lab(s) accredited for method(s)

The Marine Laboratory at Ecology's Operations Center is accredited for analyzing the chlorophyll *a* samples.

10.0 Quality Control Procedures

10.1 Table of field and laboratory QC required

Quality control (QC) procedures will be followed for field samples, field measurements using electronic instruments, and laboratory analyses.

Ecology will collect field samples for laboratory analysis of *in vitro* chlorophyll *a* concentrations. To check quality control of laboratory analysis on the field samples, Ecology will use standards and blanks for part of the procedures as outlined in SOP EAP026 (Bos, 2012). Use of standards and blanks are summarized in Table 9.

Table 9. Quality control samples, types, and frequency.

Parameter	Field		Laboratory			
	Blanks	Replicates	Check Standards	Method Blanks	Analytical Duplicates	Matrix Spikes
Field Sample						
In Vitro Chlorophyll *a*	1/batch	3	1/batch	1/batch	n/a	n/a
Electronic Sensor – Submersible Fluorometer						
In situ Chlorophyll Fluorescence	4/servicing	n/a	2/servicing	n/a	n/a	n/a
Turbidity	4/servicing	n/a	1/servicing	n/a	n/a	n/a
CDOM	4/servicing	n/a	2/servicing	n/a	n/a	n/a
Temperature	n/a	n/a	n/a	n/a	n/a	n/a
Electronic Sensor – Thermosalinograph						
Temperature	To be determined	n/a	To be determined	n/a	n/a	n/a
Conductivity	To be determined	n/a	To be determined	n/a	n/a	n/a

Field measurements using electronic sensors will be verified using seawater, deionized (DI) water, solid secondary standards, and liquid standards. The Turner Designs C3 submersible fluorometer with three optical lenses will be calibrated by Ecology. The manufacturer does not calibrate this fluorometer model but will repair it when measurements of blanks and standards do not meet requirements. Calibrations and checking sensor performance of the optical fluorometer will follow manufacturer recommendations as given in the user's manual found at http://www.turnerdesigns.com/t2/doc/manuals/998-2300.pdf. Ecology field staff will conduct sensor performance validations of the fluorometer every six weeks, depending on vessel availability and staffing. The validations will be conducted in the following order:

- Pre-cleaning measurements of seawater and then DI water.
- Clean and dry instrument, including optical lenses.
- Post-cleaning measurements using solid secondary standards for chlorophyll and CDOM fluorescence.
- Post-cleaning measurements of ambient air temperature.
- Post-cleaning measurements of DI water and then seawater.
- Post-cleaning measurements using liquid standards for chlorophyll fluorescence, turbidity, and CDOM fluorescence.

The numbers of blanks and standards to measure during each sensor servicing are given in Table 9.

In addition to routine calibrations of the optical fluorometer, Ecology plans to use a second optical fluorometer as another way to ensure quality of sensor measurements. The second fluorometer is also a Turner Designs C3 submersible fluorometer with the same set of optics. Comparisons of the two fluorometers will be conducted in a water bath of seawater, DI water, and/or liquid chlorophyll standards. Ecology may also conduct a sensor comparison test using flow-through seawater. The side-by-side comparison will occur on approximately 2-4 transects every month. Results of fluorometer comparisons will be used for validating data.

The Teledyne RDI Citadel TS-NH thermosalinograph will be calibrated per manufacturer's recommendations and repaired by the manufacturer as needed. Ecology field staff will conduct sensor performance validations of the thermosalinograph every six months, depending on vessel availability and staffing. The validations will be conducted via a bypass hose, using water of a known salinity from a laboratory. In addition, Ecology may decide to use a second thermosalinograph of the same model to conduct a sensor comparison test using flow-through seawater. The frequency of sensor comparisons will be every six months and while the ferry vessel is traveling between Seattle, WA and Victoria, B.C. Results of thermosalinograph comparisons with the fluorometer or a second thermosalinograph will be used for validating data.

Coordinates obtained from the GPS will be checked that ferry tracks are reasonable and within Puget Sound and the Strait of Juan de Fuca.

10.2 Corrective action processes

QC results may indicate problems with data during the course of the project. For field samples of *in vitro* chlorophyll *a* concentrations, the laboratory will follow prescribed procedures to resolve the problems. Options for corrective actions might include:

- Retrieving missing information.
- Re-calibrating the measurement system.
- Modifying the analytical procedures.

- Requesting additional sample collection or field measurements.
- Qualifying results.

For electronic sensors, resolving problems might include:

- Sending sensor to the manufacturer for repairs.
- Re-calibrating or redoing validation check of the sensor.
- Checking cables and/or hoses that are connected to the sensor.
- Adjusting data based on comparisons between two sensors of the same model.
- Qualifying results.

If any sensor data are corrected, correction methods will be explained in data products and reports.

11.0 Data Management Procedures

11.1 Data recording/reporting requirements

Continuous monitoring data generated by the optical fluorometer, thermosalinograph, and GPS will be recorded by external serial data loggers onto media storage cards. On a daily basis, remote connections will be initiated with the storage cards and then data files uploaded onto a cloud-computing server. Three files will be uploaded daily for a total of 1,095 files per year, dependent on all sensors functioning and meeting quality objectives. Python scripts will be used for the daily data telemetry. Using cloud computing will allow Ecology access to all data files and simultaneously allow similar data access for Integral Consulting, Inc. and APL-UW on another ferry-based project monitoring Puget Sound (Thomson, 2014).

During each servicing of the electronic sensors, field staff will record servicing observations and measurements of sensor calibrations and validations onto a water-resistant log sheet. The day's data files on the cloud-computing server will be used to estimate sensor measurements during checks of blanks and standards. Upon return to the office, project staff will input field records into a designated electronic file. Next, staff will use portions of data files copied into the designated file to calculate medians of each blank and standard measured during field servicing. Once medians are calculated and input, data will be entered into a Microsoft Access database file. This database will be used mainly as a tool to verify sensor performance and detect any potential failures. The database will be stored on a secure network server.

At each servicing, digital photographs will be taken to record debris in the sea chest once the fluorometer has been removed from it. The photographs will be stored on a secure network server.

Because there will be three separate data streams−one stream per sensor−the daily files will be merged into a single data stream, using date-time stamps recorded by each sensor and each serial data logger. Internal time drift of instruments is inevitable. Time signatures for individual sensors are synchronized by the time of power shutoff after the ship has docked in port. The

GPS unit will provide the universal time and position information for each measurement. This is critical for merging data streams prior to analysis. Ecology plans to use Python scripts to handle the daily merging of the three data streams by synchronizing date-time stamps recorded by the data loggers. The scripts will be posted with the daily files on the cloud-computing server.

Compiling the daily file into a single database for ease of querying data, calculating summary statistics, and extracting data is under development. The current plan is to use a Network Common Data Form (NetCDF) to create a georeferencing database with synchronization of date-time stamps. NetCDF is a set of software libraries and data formats that enable sharing and access of scientific data. The project database will include data QA/QC information.

Data analysis will include examining trends of water characteristics using summary statistics and temporal trends (daily, monthly, and annually). Ecology may use MATLAB, Hydstra, R, or other software but will choose one software product that is capable of handling the large amount of data and allowing staff to work with those data for analysis purposes.

11.2 Laboratory data package requirements

Laboratory results generated by the Ecology Marine Laboratory are initially recorded onto a paper form. Once project staff receives the form, laboratory results are verified to be complete and then input into electronic files which are stored on a secure network server. Any discrepancies in laboratory results and electronic files are resolved by project staff as soon as possible.

11.3 Electronic transfer requirements

Data of sensor measurements will be available in text format for ease of merging data streams and then transferring merged data into the project database. This database needs high capability of exporting data queries for use in plotting and statistical software.

Data analysis products and reports will be stored in various electronic files and on a secure, shared network server. Other project-specific files such as budget, inventories, sensor manuals, log sheets, calibration database, meeting notes, etc. will also be stored on this server.

11.4 Acceptance criteria for existing data

Data are accepted for use once initial data processing, QA/QC, and data adjustment activities confirm or reject the quality of electronic sensor operations, laboratory analyses, and field records.

11.5 EIM/STORET data upload procedures

Not applicable.

12.0 Audits and Reports

12.1 Number, frequency, type, and schedule of audits

Field audits may be required to assure that staff follow project-related SOPs and sensor manufacturers' recommendations of servicing and calibrating sensors. The frequency of field audits is dependent on results of sensor calibrations and data reviews that may indicate inconsistencies in one or more areas.

Audits of the daily telemetry feeds may be needed daily to verify that all sensors and data loggers are working. This may be as simple as checking whether all three data streams were uploaded onto the cloud-computing server. Or it may be more in-depth to evaluate if sensors' measurements of vessel positions and water characteristics are reasonable.

Water samples from this project are processed by the Marine Laboratory. No samples go to an external, analytical laboratory. Audits of the Marine Laboratory may be few, mainly to check on staff following procedures for using proper reagents, keeping the laboratory clean and organized, and processing water samples. An audit of laboratory work may be prompted if laboratory results indicate potential issues or inconsistencies.

12.2 Responsible personnel

The project manager may choose to do field audits of servicing the sensors. This will assure consistency in field methods and sensor calibrations and validations. In addition, the field servicing review will check on adherence to SOPs. Project manager and/or co-principal investigator will be responsible for verifying daily telemetry feeds and audits of the Marine Laboratory.

12.3 Frequency and distribution of report

Raw, provisional data from sensors and GPS will be posted onto the web daily. Sensor calibration results will be posted onto the web every six weeks after field servicing. Graphical plots of temporal and spatial trends will be part of the monthly Eyes Over Puget Sound summaries and routine, internal data reviews. Every six months, reporting on this project is required and due to NANOOS. Yearly products will also be generated for entities such as Puget Sound Partnership. Data will be reported as part of the Marine Waters Condition Index.

12.4 Responsibility for reports

Project manager and co-principal investigators will author the reports.

13.0 Data Verification

13.1 Field data verification, requirements, and responsibilities

The field lead will verify initial field data upon completion of each servicing. This process involves checking the field log sheet for omissions or outliers. If measurement data are missing or a measurement is suspected as an outlier, the measurement will be repeated.

After each servicing and subsequent data entries at the office, project staff will verify data entries for mistakes and outliers. This process involves checking data entries against those on field log sheets. All data entry errors that are identified will be corrected. Potential errors that are noted during data reviews will be investigated and corrected or flagged as suspect or rejected.

Continuous monitoring data from the sensors will run through a set of criteria to ensure that measurements are within range. If any sensor measurements appear to be unusual or possibly outliers, they will be investigated and then corrected or flagged as valid, estimated, or rejected. In addition, routine data reviews of statistical summaries and plots will follow a similar strategy being used for continuous mooring data (Mora et al., 2014). Results and conclusions from these data reviews will apply further QA/QC to the data.

Independent frequent sensor performance checks using independent highly calibrated pristine sensors will be used in one of these ways:

- In-line deployment using a bypass on the shaft line.
- Parallel measurements with pristine instruments next to Pier 69 (Clipper Navigation's dock) during ship movements in or out of the docking slip.
- Overlapping transects of ships of opportunity (e.g., King County, Shannon Point Marine Center, Ocean Research College Academy) in Elliott Bay, Triple Junction, or the Straits of Juan de Fuca.

The best approach for these tests will be evaluated as planned test comparisons become available in the first year of the project.

Data reductions, summaries, reviews, and reporting will provide additional avenues into verifying field data.

13.2 Lab data verification

As the only laboratory data will come from Ecology's Marine Laboratory, data entries will be verified by project staff. This process involves checking data entries against those on laboratory log sheets and checking calculations of the final chlorophyll *a* concentrations of each sample.

13.3 Validation requirements, if necessary

On a monthly basis, staff perform a group review of plots and statistical summaries of data. Staff members review sensor data sets, documenting problems, and applying QC qualifier codes as necessary. All flagged data are presented, reviewed, and discussed by several staff members and then 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 will be re-assessed in the context of the annual summary and then finalized once all QA/QC activities and validation are complete.

Data collected by the fluorometer and thermosalinograph will be validated by conducting sensor-to-sensor comparisons. Such comparisons may use either flow-through seawater or water of known salinity.

14.0 Data Quality (Usability) Assessment

14.1 Process for determining whether project objectives have been met

Data from field servicings, sensor maintenance and repairs, laboratory results, and continuous monitoring sensors provide information to determine if MQOs have been met. This determination will include reviews of sensor functionality, precision, accuracy, completeness, representativeness, and comparability. If data criteria are not met, project staff will decide if affected data should be qualified or rejected before final analysis and reporting.

14.2 Data analysis and presentation methods

The resulting continuous data will be plotted in temporal graphs and on satellite images. They will also be summarized by month and year for comparison with the monthly results from the marine waters profiling and mooring projects. Additional data analysis and products may include tables and graphics which follow relevant statistical and analytical research published in peer-reviewed scientific literature. These products will be further developed as data are collected, to suit the needs of the scientific community and public.

14.3 Treatment of non-detects

For laboratory data (chlorophyll *a* samples), only sample results quantified at concentrations at least three times greater than the corresponding results in the method blank and in the field blank samples are considered "detected". 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

As data are collected, reduced, summarized, and analyzed, project staff will re-examine current parameters being measured and determine whether less or additional parameters should be considered. Sample measurement frequency will also be considered.

The sampling design may need further evaluation, as Ecology addresses questions and concerns about water quality of Puget Sound.

14.5 Documentation of assessment

Reports will include a summary of the data quality assessment findings. These reports will provide information on the data quality and usability decisions based on QA/QC procedures.

15.0 References

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16.0 Appendix. Glossaries, Acronyms, and Abbreviations

Glossary of General Terms

Acetone: A chemical compound that is a volatile and flammable liquid ketone. It is being used to extract chlorophyll pigments from algal cells.

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

Centrifuge: A laboratory instrument that spins samples to aid in separation of liquids and/or solids.

Chlorophyll *a*: Photosynthetic pigment produced by plants, algae, and phytoplankton.

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.

Cloud computing: A type of computer network infrastructure that allows for storage of data and programs on the Internet rather than a local hard drive or network server. This allows sharing of files by more than one group that cannot share local, internal network servers.

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.

Emission: When a cell or organism is exposed to light, it produces fluorescing light.

Excitation: Absorption of fluorescent light by a cell or organism.

Fluorometer: An environmental sensor that produces fluorescing light to measure fluorescing emission of a cell or organism.

***In vitro*:** In biology, organisms are studied in an artificial environment such as a culture medium.

***In situ*:** In biology, organisms are studied in their natural environment.

Median: The numerical value that is in the middle of a data range and separates two halves of the data range.

Niskin: A type of water grab sampler named after inventor Shale Niskin in 1966. It is normally used in oceanography studies to sample the water column for plankton and physical water characteristics.

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

Python: In this project, Python refers to a programming language.

Reach: A specific portion or segment of a stream.

Salinity: A measurement of salt in marine and estuarine waters.

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

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

Thermosalinograph: An environmental sensor that measures water temperature and conductivity.

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.

Acronyms and Abbreviations

4G	Fourth generation of mobile telecommunications technology
APL-UW	Applied Physics Laboratory, University of Washington
B.C.	British Columbia, Canada
CDOM	Colored dissolved organic matter
CF	Compact flash memory card for portable devices
CWL	Center wavelength
DQO	Data quality objective
e.g.	For example
EAP	Environmental Assessment Program, Washington State Department of Ecology
EAPMW	A SQL Server database under development for EAP
Ecology	Washington State Department of Ecology
EIM	Environmental Information Management database
EOPS	Eyes Over Puget Sound, a monthly release of data on Puget Sound and coastal bay marine water conditions
EPA	U.S. Environmental Protection Agency
et al.	And others
GF/F	A type of glass microfiber filters
GPS	Global Positioning System

HAB	Harmful algal bloom
HPLC	High-performance liquid chromatography
HUC	Hydrologic Unit Code
i.e.	In other words
ID	Identification
LED	Light emitting diode, a type of light source
MQO	Measurement quality objective
NANOOS	Northwest Association of Networked Ocean Observing System
NetCDF	Network common data form
PSEMP	Puget Sound Ecosystem Monitoring Program
PST	Pacific Standard Time
QA	Quality assurance
QA/QC	Quality assurance/quality control
QAMP	Quality assurance monitoring plan
QAPP	Quality assurance project plan
RSD	Relative standard deviation
SD	Secure digital memory card for portable devices
SOP	Standard operating procedures
USA	United States of America
Wi-Fi	Wireless network to allow electronic devices exchange data
WRIA	Water Resource Inventory Area

Units of Measurement

°C	degrees centigrade
°F	degrees Fahrenheit
hr	hour
km	kilometer, a unit of length equal to 1,000 meters
m	meter
mg	milligram
mg/L	milligrams per liter (parts per million)
mi	miles
mL	milliliter
mm	millimeter
mph	miles per hour
mS/cm	millisiemens per centimeter, a unit of conductivity
nm	nanometer
NTU	nephelometric turbidity units
ppb	parts per billion
psu	practical salinity units
sec	second
ug/L	micrograms per liter (parts per billion)

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

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

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

Data validation: An analyte-specific and sample-specific process that extends the evaluation of data beyond data verification to determine the usability of a specific data set. It involves a detailed examination of the data package, using both professional judgment, and objective criteria, to determine whether the MQOs for precision, bias, and sensitivity have been met. It may also include an assessment of completeness, representativeness, comparability and integrity, as these criteria relate to the usability of the data set. Ecology considers four key criteria to determine if data validation has 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 Project Plan (QAPP): A document that describes the objectives of a project, and the processes and activities necessary to develop data that will support those objectives. (Kammin, 2010; Ecology, 2004)

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

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

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

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

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

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

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

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

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

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

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

Split Sample: 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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