QUALITY ASSURANCE PROJECT PLAN

SQUAXIN ISLAND TRIBE LONG-TERM WATER QUALITY MONITORING PROGRAM

Prepared for
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Prepared by
Herrera Environmental Consultants, Inc.

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INTRODUCTION

Management of Squaxin Island Tribe (SIT) natural resources is central to the Tribe's existence, and it involves ensuring the requisite environmental quality necessary to sustain those resources, consistent with Treaty and federal court rulings. The Tribe carries out this responsibility as a co-manager with the State of Washington. The current condition of natural resources in South Salish Sea is tenuous, and falls far short of tribal expectations and government obligations. In order to address these shortcomings, the SIT natural resource department has implemented a framework consisting of goals, fundable initiatives, and special policy initiatives. Central to the effort is long-term water quality and flow monitoring. A narrative describing these components is attached in Appendix A.

For more than a decade, SIT has monitored water quality and discharge at the mouths of a number of area streams. The purpose of this monitoring was to detect pollutants, particularly fecal coliform bacteria that can impact the harvestability of shellfish. The motivation behind this monitoring effort was to serve as an "early warning system" so that if high fecal coliform concentrations were detected in the streams, prompt corrective actions could be taken before marine water contamination reached levels that prohibit shellfish harvest. This monitoring has amassed a large quantity of useful data. However, throughout the course of the project several monitoring locations were changed, abandoned, or may not have provided comparable data.

Moving forward, SIT is streamlining its monitoring program by reducing the number of monitoring locations, and incorporating continuous measurement of nitrate and turbidity at one location. These changes will help produce a robust, long-term dataset that not only will continue providing early detection of fecal coliform bacteria problems, but will also facilitate seasonal and long-term trend analysis capable of detecting changes in water quality in response to climate change and watershed alteration. This represents an expansion of scope from harvest safety to a broader assessment of watershed health.

The goal of this monitoring plan is to document procedures used for data sample collection, laboratory analysis, and data analysis strategies to ensure high quality, scientifically defensible results. This document includes the following:

- **Project Description** – Project goals and objectives, and the information required to meet the objectives.
- **Organization and Schedule** – Project roles and responsibilities, and the schedule for completing the work.
- **Measurement Quality Objectives** – Performance (or acceptance) thresholds for collected data.
- **Experimental Design** – The sampling process design for the study, including sample types, monitoring locations, and sampling frequency.

- **Field Procedures** – A detailed description of sampling procedures and associated equipment requirements.
- **Laboratory Procedures** – Laboratory procedures that will be performed on collected samples.
- **Quality Control** – Quality control (QC) requirements for both laboratory and field measurements.
- **Data Management Procedures** – How data will be managed from field or laboratory recording to final use and archiving.
- **Audits and Reports** – The process that will be followed to ensure this Quality Assurance Project Plan (QAPP) is being implemented correctly and the quality of the data is acceptable.
- **Data Verification and Validation** – The data evaluation process, including the steps required for verification, validation and data quality assessment.
- **Data Quality (Usability) Assessment** – The procedures that will be used to determine if collected data are of the right type, quality, and quantity to meet project objectives.

PROJECT DESCRIPTION

The purpose of this monitoring effort is to continue protecting the opportunity to harvest shellfish at all the usual and accustomed grounds and stations reserved in the 1854 Treaty of Medicine Creek. The treaty fishing area for SIT includes all waters south of the Tacoma Narrows at the headwaters of the Salish Sea (South Puget Sound). Tribal shellfish beds currently harvested are concentrated in Oakland Bay/Hammersley Inlet, North Bay/Case Inlet, Little Skookum Inlet and Squaxin Island. These areas are shown with monitoring station locations in Figure 1.

Continued, safe and abundant shellfish harvest is dependent on a number of environmental factors. One of the most serious threats is nonpoint source pollution originating from failing septic systems and poorly managed livestock operations that may contribute concentrated loadings of fecal coliform bacteria to marine waters of tribal shellfish harvest areas.

To document and detect bacteria problems and to continue building a long-term water quality record, SIT will monitor 18 stations located on 16 streams. The majority of the sampling stations are at the mouths of streams that discharge into active Tribal shellfish harvest areas. Most of these stations are already monitored as part of the "Shellfish Early Warning System." On two streams, upstream stations will be established for the purpose of detecting water quality changes occurring within forested watersheds.

At all 18 stations, fecal coliform sampling and field measurements of temperature, pH, dissolved oxygen (DO), and conductivity will be conducted on 12 monthly events per year. These data will provide an early warning of increasing indicator bacteria loading so that necessary corrective actions can occur before any shellfish harvest downgrades are necessary.

At eight stations, water level and temperature will be measured continuously using *in situ* meters, and stream discharge measurements will be made to convert water level data to continuous flow records. These measurements will be made by the US Geological Survey (USGS) at one of the eight stations, and the data obtained will be evaluated for this program.

At one station, for the period of at least a year, *in situ* meters will be deployed to continuously measure turbidity and nitrate concentrations. Samples at this station will also be collected for laboratory analysis of suspended sediment concentration (SSC) to correlate *in situ* turbidity readings with SSC, and for nitrate+nitrite nitrogen to calibrate *in situ* nitrate readings.

While the primary purpose of this effort remains bacteria monitoring, the other data collected will be valuable for detecting long-term trends resulting from climate change and development in the surrounding watersheds. Spatial and temporal trends in water quality and flow data will be evaluated at all stations using statistical analyses and comparisons to water quality criteria. At one station each year, continuous flow data coupled with continuous nitrate and turbidity data will be used to estimate loadings of nitrate and suspended sediment (through correlation with turbidity). Data from the first year will be used to determine where and how to operate the nitrate and turbidity probes in the future. It is anticipated that the nitrate probe will be moved each year to a new station with a stream gauge. Alternatively, nitrate probe operations may change to shorter periods of use at multiple stations per year for source tracking purposes.

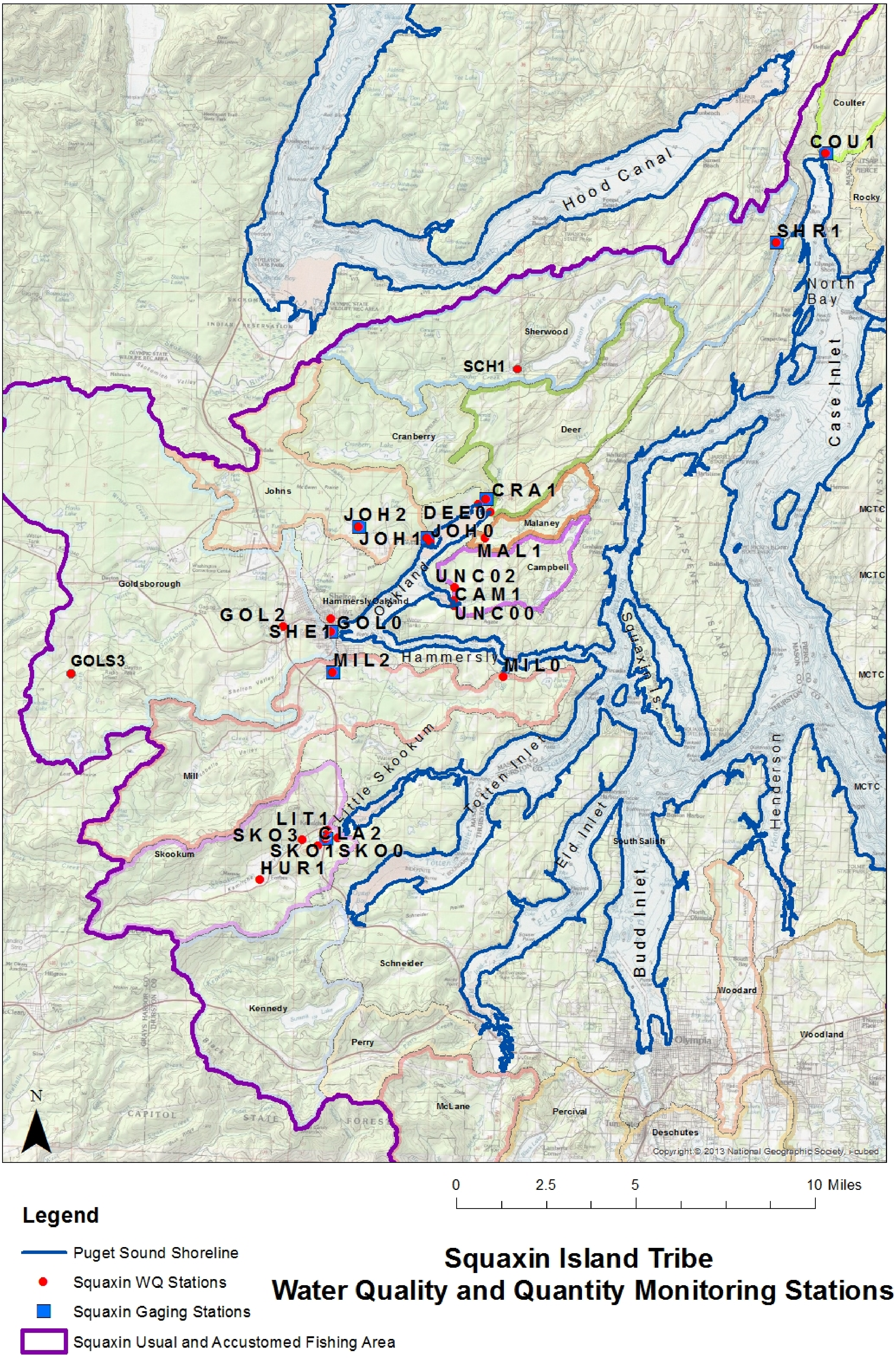

Figure 1. Squaxin Island Tribe Long-Term Water Quality Monitoring Program Stations.

PROJECT ORGANIZATION AND SCHEDULE

This section describes how the project is organized, key personnel, and the project schedule.

ORGANIZATION AND KEY PERSONNEL

The long-term water quality monitoring program will be implemented by various SIT staff and laboratory analysis will be conducted by the Washington Department of Ecology Manchester Laboratory. Responsibilities of key personnel are shown in Table 1.

Table 1. SIT Long-Term Stream Monitoring Project Personnel and Responsibilities.

Personnel	Organization/Title	Email/Phone	Responsibilities
Jeff Dickison	Squaxin Island Tribe/ Assistant Director of Natural Resources	jdickison@squaxin.us 360-432-3815	SIT Program Manager responsible for overall contract management.
Erica Marbet	Squaxin Island Tribe/ Water Resources Biologist	emarbet@squaxin.us (360) 432-3804	SIT Project Manager responsible for data collection, preparation of project reports, coordination of sample delivery and analyses by laboratories, assistance with field sampling, and oversee contract.
Joe Puhn	Squaxin Island Tribe/ Resource Technician III	jpuhn@squaxin.us (360) 463-0775	SIT Lead Field Sampler and Data Manager responsible for collection of water samples and flow data, and management of all field and laboratory data.
Brian McTeague	Squaxin Island Tribe/ Quantitative Services Manager	bmcteague@squaxin.us 360-432-3800	SIT Quality Assurance Officer responsible for conducting QA/QC review of field and laboratory data.
Nancy Rosenbower	Washington Department of Ecology Manchester Laboratory/ Laboratory Manager	nros461@ecy.wa.gov (360) 871-8827	Laboratory Manager responsible for analysis of all laboratory samples

SCHEDULE

The monitoring program schedule is summarized in Table 2.

Table 2. Project Schedule by Water Year (October through September).

Task	Activity	Schedule
Hydrologic Monitoring	Continuous flow and precipitation data collection	Monthly download/maintenance in October through September
	Discharge measurement	Up to 12 events/year in October through September
	Data validation/management	Within 14 days of data collection
Water Quality Monitoring	Water quality sampling and field parameter measurement	12 events/year on a monthly basis regardless of flow conditions
	Continuous temperature, nitrate, and turbidity measurement	Monthly download/maintenance in October through September
	Data validation/management	Within 60 days of field data collection
Laboratory Analysis	Laboratory reports	Within 30 days of sampling
	Data validation/management	Within 60 days of reporting
Annual Report	Draft report	January
	Final report	February

QUALITY OBJECTIVES

The goal of this QAPP is to ensure that the data collected for this study are scientifically accurate, useful for the intended analysis, and legally defensible. To achieve this goal, the collected data will be evaluated relative to the following indicators of quality assurance:

- **Precision:** A measure of the variability in the results of replicate measurements due to random error
- **Bias:** The systematic or persistent distortion of a measurement process that causes errors in one direction (i.e., the measured mean is different from the true value)
- **Representativeness:** The degree to which the data accurately describe the conditions being evaluated based on the selected sampling locations, sampling frequency and duration, and sampling methods
- **Completeness:** The amount of data obtained from the measurement system
- **Comparability:** The ability to compare data from the current study to data from other similar studies, regulatory requirements, and historical data

Measurement quality objectives (MQOs) are performance or acceptance criteria that are established for each of these quality assurance indicators. These MQOs are described below in separate subsections for continuous hydrologic and water quality data, and discrete water quality data.

CONTINUOUS HYDROLOGIC AND WATER QUALITY DATA

Continuous monitoring for this performance verification includes hydrologic monitoring and water quality monitoring. Continuous water quality monitoring will consist of data collected by a SUNA V.2 (SUNA) nitrate probe, a Forest Technology Systems DTS12 turbidity sensor, and HOBO temperature loggers. MQOs for SUNA nitrate monitoring are described in the Standard Operation Procedure presented in Appendix B. MQOs for continuous turbidity and temperature monitoring are based on manufactures specifications combined with SOPs developed by the Washington Department of Ecology for *in situ* turbidity (Appendix C) and temperature (Appendix D) monitoring.

Hydrologic monitoring involves continuous measurements of water level and precipitation, and discrete measurements of discharge taken over a range of flow conditions. Rating curves will be developed based on discharge as a function of water lever, and will be used to convert each water level record to discharge. MQOs for hydrologic monitoring are based on SOPs developed by the Washington Department of Ecology for stream gauge measurement, stream discharge measurement, and correction of water level data (Appendix E).

MQOs for continuous water quality and hydrologic data are expressed in terms of bias, representativeness, completeness and comparability. Because it is difficult to obtain repeat measurements from continuous monitoring equipment during continuously changing site conditions, precision cannot be readily assessed.

Bias

The precision of continuous monitoring data will be assessed based on comparisons of monitoring equipment readings to an independently measured "true" value. In the case water level data, the true value will be derived from manual measurements of water level that are obtained from a staff gauge at each monitoring location. In the case of water quality data, the true value will be derived from laboratory measurements of the measured parameters. These manual measurements will be made in conjunction with routine visits to each monitoring location.

If the monitoring equipment is not affected by drift or other operational problems, the difference between the equipment's reading and the manual measurement ("instrument drift") should remain at zero over time and varying conditions. Bias of water quality and level data will be assessed based on the change in the instrument drift value relative to all previous measurements. Specifically, a change in the drift value of plus or minus two standard deviations relative to the mean from all previous measurements will trigger an assessment of the monitoring equipment to determine proper functioning.

Completeness

Completeness will be assessed based on the occurrence of gaps that may occur in the data record for all monitoring equipment. The associated MQO is less than 10 percent of the total data record missing due to equipment malfunctions or other operational problems. Completeness will be ensured through routine maintenance of all monitoring equipment and immediate implementation of corrective actions if problems arise.

Comparability

Standard monitoring procedures, units of measurement, and reporting conventions will be applied to meet the goal of data comparability.

DISCRETE WATER QUALITY DATA

The overall MQO for water quality data is to ensure that data of a known and acceptable quality are obtained. All measurements will be performed to yield consistent results that are representative of the media and conditions measured.

Quality assurance indicators for laboratory and field data are expressed in terms of precision, bias, representativeness, completeness, and comparability and reporting limit. The associated MQOs are defined in the subsections below and summarized in Table 3. Note that the term "reporting limit" in this document refers to the practical quantification limit established by the laboratory, not the method detection limit.

Table 3. Summary of Measurement Quality Objectives and Required Reporting Limits of Field and Laboratory Parameters.					
Parameter	**Lower Reporting Limit/Unit**	**Meter Accuracy**	**Laboratory Duplicate (RPD)**	**Matrix Spike (% recovery)**	**Control Sample (% recovery)**
Field Parameters[a]					
Temperature	0.1°C	± 0.2°C	NA	NA	NA
pH	2 units	± 0.2 units	NA	NA	NA
Conductivity	2 uS/cm	± 0.1%	NA	NA	NA
Dissolved oxygen	0.1 mg/L	± 0.2 mg/L	NA	NA	NA
Turbidity	1.0 NTU	± 2%	NA	NA	NA
Nitrate nitrogen	0.010 mg/L	± 10%	NA	NA	NA
Laboratory Parameters					
Fecal coliform bacteria	5 CFU/100 mL	NA	40	NA	NA
Nitrate+nitrite nitrogen	0.010 mg/L	NA	20	75–125	80–120
Turbidity	1.0 NTU	NA	20	75–125	80–120
Suspended sediment	1.0 mg/L	NA	20	75–125	80–120

[a] Field parameters that will be measured with a handheld meter except turbidity and nitrate will be measured with an deployed meter. MQOs will be assessed relative to manufactures specifications and calibration and verification procedures.

CFU/100 mL = colony forming unit per 100 milliliters.

mg/L = milligrams per liter.

uS/cm = microsiemens per centimeter.

NA = not applicable.

RPD = relative percent difference.

Precision

Precision will be assessed based on the analyses of laboratory duplicates. One laboratory duplicate will be analyzed with each batch of samples. In this case, a batch represents the total number of samples collected during one sampling event.

Two levels of precision for duplicate analyses will be evaluated using reported values for parameters of concern. The relative percent difference (RPD) of laboratory duplicates will be less than or equal to 20 percent (35 percent for fecal coliform bacteria) for values that are greater than 5 times the detection limit, and ± 2 times the detection limit for values less than or equal to 5 times the detection limit.

Precision in these samples will be quantified based on their RPD:

$$RPD = \frac{(C_1 - C_2) \text{ x } 100\%}{(C_1 + C_2) / 2}$$

Where: RPD = relative percent difference

C_1 = larger of two values

C_2 = smaller of two values

Specific MQOs for laboratory duplicates are defined by analysis method in Table 3.

Bias will be assessed based on analyses of method blanks, matrix spikes (MS), and laboratory control samples (LCS). Bias in MS and LCS will be quantified based on percent recovery or the average (arithmetic mean) of the percent recovery. Percent recovery for MS will be calculated using the following equation:

$$\%R = \frac{(S - U) \times 100\%}{C_{sa}}$$

Where: %R = percent recovery

S = measured concentration in spike sample

U = measured concentration in unspiked sample

C_{sa} = actual concentration of spike added

Percent recovery for LCS will be calculated using the following equation:

$$\%R = \frac{M}{T} \times 100\%$$

Where: %R = percent recovery

M = measured value

T = true value

Specific MQOs for MS and LCS are defined in Table 3 by analysis method.

Representativeness

Sample representativeness will be ensured by employing consistent and standard sampling procedures identified in this QAPP.

Completeness

Completeness will be assessed based on the percentage of specified samples (listed in this QAPP) collected. The completeness goal shall be 95 percent. Completeness for acceptable data is defined as the percentage of acceptable data out of the total amount of data generated. Acceptable data is either data that passes all quality control criteria, or data that may not pass all quality control criteria but has appropriate corrective actions taken.

Comparability

Standard sampling procedures, analytical methods, units of measurement, and reporting limits will be applied in this study to meet the goal of data comparability. The results will be tabulated in standard spreadsheets to facilitate comparison with other study results and water quality threshold limits (e.g., WAC 173-201A).

Reporting limits

Reporting limits for laboratory analyses have been set to allow comparison with Washington State and EPA surface water quality standards, as well as historical data (see Table 3).

The fecal coliform bacteria analysis reporting limits and resulting methodology have been chosen so that data collected for this study is accurate and can be compared to historical data collected by SIT and other agencies (e.g., Mason County, Ecology). The range of reporting values is dependent on the sample dilutions utilized. Two filter volumes (2 and 20 milliliters) will be used for each analysis to ensure that a broad range of concentrations can be characterized. The lower reporting limit for fecal coliform bacteria enumeration analysis will be 5 CFU/100 mL and the upper reporting limit will be 10,000 CFU/100 mL. At the discretion of the quality assurance officer, sample dilution volumes may be adjusted if bacteria concentrations differ from those anticipated.

EXPERIMENTAL DESIGN

This section describes the experimental design that will be used for this study.

MONITORING STATION LOCATIONS

A total of 24 stations on 16 streams were selected for flow and/or water quality monitoring. Continuous flow and temperature monitoring will be conducted on 8 stations; fecal coliform and water quality parameter monitoring will be conducted on 18 stations; and continuous nitrate and turbidity monitoring will be conducted on 1 station (see Figure 1).

Table 4 shows the measured parameters and the length of the existing data record for each selected monitoring station. For some streams, flow monitoring will be conducted at a different location than water quality monitoring. Original station locations were retained for consistency and comparisons with historical data. It is not necessary to co-locate flow and water quality measurements at these stations because trends in flow and water quality will be evaluated separately, and not used to calculate pollutant loadings at stations not located in close proximity.

The selected stations were chosen from a list of 34 potential locations. Monitoring stations were prioritized based on the following criteria:

- Current SIT monitoring station
- Long-running data record
- Known problems with fecal coliform bacteria (in stream or nearby marine waters)
- Below potential fecal sources (e.g., pasture land)
- Not already monitored by another entity
- Below tribal land
- Concurrent with existing stream gauging station

The following existing routine stations were eliminated from the monitoring program to conserve monitoring time and costs:

- Uncle Johns Creek Upstream (UNCO2) – water quality station started in 2004
- Twin Rivers (TR24) – water quality station started in 2006
- Rocky Creek (ROC1) – water quality station started in 2012

Table 4. Squaxin Island Tribe Long-Term Stream Monitoring Program Summary.

Region	Stream – Station Code	Flow Gauge/ Temp. Logger	Nitrate/ Turbidity Sensor	WQ Meter	Lab Fecal	Lab Nitrate/ Turbidity/ SSC	Flow Begin Year	Fecal Begin Year	Location
Hammersley	Mill – MIL0	–	–	X	X	–	2003	2004	Mouth
Hammersley	Mill – MIL2	X	–	–	–	–	2003	–	5 miles up from MIL0
Oakland	Campbell – CAM1	–	–	X	X	–	–	2005	Mouth
Oakland	Coulter – COU1	X	–	X	X	–	2005	2012	Mouth
Oakland	Cranberry – CRA0	–	–	X	X	X	2003	2006	Mouth
Oakland	Cranberry – CRA1	X	X			–	2003	2004	400 feet up from CRA1
Oakland	Deer – DEE0	–	–	X	X	–	–	2004	Mouth
Oakland	Goldsborough – GOL0	–	–	X	X	–	2004	2004	Mouth
Oakland	Goldsborough – GOL2	X[a]	–	–	–	–	2004	–	1.4 miles up from GOL0
Oakland	Goldsborough – GOLS3	–	–	X[b]	X[b]	–	–	–	New background on South Fork at 4500 Road
Oakland	Johns – JOH0		–	X	X	–	2005	2004	Mouth
Oakland	Johns – JOH1	X	–	–	–	–	2005	2004	200 feet up from JOH0
Oakland	Johns – JOH2	X	–	–	–	–	2003	–	2 miles up from JOH0
Oakland	Malaney – MAL1	–	–	X	X	–	–	2004	Mouth
Oakland	Shelton – SHE1	–	–	X	X	–	–	2004	Mouth
Oakland	Uncle Johns – UNC00	–	–	X	X	–	–	2004	Mouth
Skookum	Hurley – HUR1	–	–	X	X	–	–	2006	Mouth
Skookum	Little – LIT1	–	–	X	X	–	–	2006	Mouth
Skookum	Skookum – SKO0	–	–	X	X	–	–	2006	Below LIT1
Skookum	Skookum – SKO1	X	–	–	–	–	2004	–	Above LIT1
Skookum	Skookum – SKO3	–	–	X	X	–	2004	2006	0.8 miles up from SKO1
Skookum	Clary – CLA2	–	–	X	X	–	–	2014	Mouth
Case	Schumocher – SCH1	–	–	X[b]	X[b]	–	–	–	New background at Mason Lake Rd
Case	Sherwood-SHR1	X	–	X	X	–	2006	2012	0.5 miles up from mouth
Total Stations	**24**	**8**	**1**	**18**	**18**	**1**	**–**	**–**	

[a] Monitoring and rating curve development by USGS.

[b] New upstream water quality monitoring station added in 2016 to represent drainage from undeveloped land.

Flow Gauge = Continuous flow gauge and measurements for rating curve.

Temp. Logger = Continuous HOBO temperature data logger.

Nitrate Sensor = Continuous SUNA V2 UV nitrate sensor.

Turbidity Sensor = Continuous Forest Technology Systems DTS12 turbidity sensor.

WQ Meter = 12 monthly grabs/year for temperature, pH, dissolved oxygen, and conductivity with a YSI multimeter in field.

Lab Fecal = 12 monthly grabs/year for fecal coliform bacteria by lab.

Lab Nitrate/Turbidity/SSC = 12 monthly grabs/year for nitrate+nitrite nitrogen, turbidity, and suspended sediment concentration by lab.

The following stations were added to the monitoring program to provide two stations that reflect conditions on undeveloped land and are representative of background stream conditions for comparison to trends in the other stations affected by human land uses:

- South Fork Goldsborough Creek (GOLS3) – new water quality station located on the South Fork where existing land cover is primarily forest
- Schumocher Creek (SCH1) – new water quality station located on a small stream where existing land cover is primarily forest

Flow Monitoring

Seven of the eight flow gauging stations have been previously established under another QAPP (SIT 2009), and one station (GOL2) was established and is operated by the US Geological Survey (USGS) (see Table 4). Flow gauging station establishment for the purposes of this project will consist of a verification of equipment, station configuration, and procedures. The flow gauges will be used to obtain a continuous record of discharge throughout the project duration. At each gauging station, there will be a staff gauge for obtaining a manual measurement of water level at a fixed location within the stream channel. Data-logging pressure transducers will be installed adjacent to staff gauges, to facilitate the continuous collection of water level data at a 5-minute logging interval. The pressure transducer will be housed in a vandal-resistant stilling well submerged within the stream channel. The specific configuration of this equipment at each monitoring location will be documented by the project team on standardized forms. Each flow gauging station will be visited on a monthly or more frequent basis to check the operational status of the data loggers at each monitoring location and to upload the associated water level data.

To convert the water level data to estimates of discharge, stream discharge rating curves will be developed for each monitoring location based on manual measurements of discharge that are made during each sampling event. Based on this schedule, it is anticipated that a minimum of 12 discharge measurements will be obtained for each station to facilitate rating curve development. Excel spreadsheets to develop stream discharge rating curves using USGS protocols from the manual measurements of discharge at each monitoring location. The sampling team will also collect channel cross-section information from each monitoring location once during the summer and twice between October and April to determine if there have been substantial changes in channel geometry due to scour or other fluvial processes that would warrant development of a new rating curve.

Water Quality Monitoring

SIT's long-term monitoring has several related water quality monitoring components. The following identifies the frequency of monitoring and type of sample for each component.

Fecal Coliform and Conventional Field Parameters

Twelve grab samples will be collected from each water quality monitoring station per year. Samples will be collected on a monthly basis regardless of flow conditions. Temperature, pH, conductivity, and dissolved oxygen will be measured with a handheld multi-parameter meter concurrent with fecal coliform grab sample collection.

This sampling schedule has been implemented by SIT since inception of the monitoring program and will be retained to maximize the ability to detect long-term trends in parameter values using statistical tests accounting for seasonal trends in the data. An alternative sampling schedule was considered that focused on critical periods corresponding to only winter and summer months when fecal coliform concentrations are expected to be most representative of wet and dry conditions. However, changes to this type of sampling schedule would reduce the ability to detect statistically significant long-term trends in fecal coliform and field parameters.

Temperature

Water temperature will be continuously monitored at eight flow monitoring stations (see Table 4) using HOBO temperature loggers. Specific procedures for temperature logger deployment and operation are described in an SOP prepared by Ecology (Appendix D).

Nitrate

During the first year, nitrate will be continuously monitored at the mouth of Cranberry Creek at station CRA0 using a SUNA V.2 *in situ* nitrate probe. Specific procedures for the SUNA probe deployment and operation are described in the SOP prepared for the program (Appendix B). Nitrate grab samples will be collected 12 times each year during fecal coliform and field parameter sampling at station CRA0 for calibration and verification of the SUNA Probe operation.

It is anticipated that the nitrate sampling station will be rotated between stream stations in subsequent years. SIT will evaluate the first year results to determine which new station will be selected for another year of nitrate monitoring. In addition, an alternative nitrate monitoring design will be considered that includes shorter periods of use at multiple stations per year for source tracking purposes.

Turbidity and Suspended Sediment Concentration

Turbidity will be continuously monitored at the mouth of Cranberry Creek at station CRA0 using Forest Technology Systems DTS12 turbidity sensor. Turbidity and suspended sediment concentration will be measured from grab samples collected 12 times each year during fecal coliform and field parameter sampling at station CRA0. The purpose of turbidity sampling is for calibration and verification of the turbidity sensor. The purpose of the suspended sediment sampling is to establish a correlation between the continuous turbidity measurements and suspended sediment concentrations as described in an SOP prepared by Ecology (Appendix C).

It is anticipated that the turbidity and suspended sediment sampling station will be rotated between stream stations in subsequent years. As for nitrate, SIT will evaluate the first year results to determine which new station will be selected for another year of turbidity and suspended sediment monitoring. In addition, an alternative turbidity and suspended sediment monitoring design will be considered that includes shorter periods of use at multiple stations per year for source tracking purposes.

Data Analysis

Data collected throughout this study will be used for a variety of purposes. As the project progresses utility in the data may be recognized and statistical analyses beyond those listed below may be appropriate. At the outset though, the data collected will be analyzed as follows:

- Calculate summary statistics for temperature, pH, conductivity, dissolved oxygen, and fecal coliform bacteria concentrations for each monitoring station by season (i.e., summer and winter) that include minimum, maximum, mean, median, 25th percentile, and 75th percentile.

- Calculate and compare the geometric mean and 90th percentile of fecal coliform bacteria concentrations for each season (summer and winter) to Washington State water quality criteria.

- Perform temporal trend analysis using a non-parametric statistical test (e.g., Seasonal Mann Kendall) on discrete data for fecal coliform bacteria and conventional water quality parameters to determine whether there is a statistically significant shift in those parameters over time.

- Perform temporal trend analysis using a non-parametric statistical test (e.g., Seasonal Mann Kendall) on continuous flow and temperature data to determine whether there is a statistically significant shift in those parameters over time.

- Perform regression analysis of turbidity and SSC data, and apply model representing the relationship between SSC and turbidity to the continuous turbidity record to produce a continuous record of SSC data at station CRA0 (or where the turbidity meter is deployed in the future).

- Compute monthly and seasonal loading rates for nitrate and suspended solids concentration at station CRA0 (or where the turbidity meter is deployed in the future).

Data from the continuous flow monitoring will be processed to calculate the following indicators for evaluating hydrologic impacts from urban development and climate change as described in DeGasperi et al. (2009):

- **High pulse count**: occurrence of daily average flows that are equal to or greater than a threshold set at twice (2 times) the long-term daily average flow rate.

- **High pulse frequency**: number of days each water year that discrete high flow pulses occur.

- **High pulse count duration**: annual average duration of high flow pulses during a water year.

- **High pulse count range**: range in days between the start of the first high flow pulse and the end of the last high flow pulse during a water year.

- **Low pulse count**: occurrence of daily average flows that are equal to or less than a threshold set at 50 percent of the long-term daily average flow rate.

- **Low pulse count frequency**: number of times each calendar year that discrete low flow pulses occurred.

- **Low pulse count duration**: annual average duration of low flow pulses during a calendar year.

- **Low pulse count range**: range in days between the start of the first low flow pulse and the end of the last low flow pulse during a calendar year.

- **Low flow frequency statistics:** 7 and 30 consecutive-day low flow rates with recurrence intervals of 2 and 10 years.

- **Richards-Baker (RB) flashiness index**: a dimensionless index of flow oscillations relative to total flow based on daily average discharge measured during a water year.

- **TQ Mean**: the fraction of a year that mean daily discharge exceeds annual mean discharge.

- **Total flow volume**: total discharge volume over a water year.

Trends over time at each monitoring station will be evaluated using parametric (Pearson's r) and nonparametric (Kendall's tau or Spearman's rho) tests of correlation between these indicators and time. Statistical significance of the correlation coefficients will be evaluated based on an alpha-level of 0.05 for a two-tailed test.

FIELD PROCEDURES

This section presents field procedures that will be employed for the SIT Long-Term Monitoring Program.

SAMPLE COLLECTION

Water samples will be collected by hand from each of the 18 water quality monitoring locations using pre-cleaned bottles supplied by the laboratory (Washington Department of Ecology Manchester Laboratory). The Field Sampler will use aseptic techniques for collecting water samples. Water samples will be collected by submerging each sample bottle to mid-depth and orienting the bottle opening upstream (against flow) while filling. The sample bottle will be removed when the bottle is 90 percent full and sealed with the cap. Water samples will be collected from the thalweg or center of the stream channel. If a stream is unwadable during high flow conditions, a pole will be used to position the sample bottle in the thalweg of the channel for sample collection purposes.

The collected water samples will be immediately stored in a cooler with ice at a temperature less than 4°C (Celsius). The will be delivered to the laboratory on the day of collection, or on the following morning if collected during the evening. Table 5 presents the sample bottle, holding time, and preservation for the four sampled parameters.

Table 5. Sample Bottle, Holding Time, and Preservation Summary.

Parameter	Container Type	Sample Bottle Volume (mL)	Maximum Holding Time	Preservation
Fecal coliform bacteria	Sterile plastic bottle	250	24 hours	Cool to 4°C
Nitrate + nitrite nitrogen	HDPE Bottle	125	28 days	H_2SO_4, Cool to 4°C
Turbidity	HDPE Bottle	500	48 hours	Cool to 4°C
Suspended sediment	HDPE Bottle	1,000	NA	Cool to 4°C

Temperature, pH, dissolved oxygen, and conductivity will be measured using a handheld YSI multiparameter water quality meter. All probes will be calibrated immediately prior to each sampling event according to manufacturer calibration procedures. Field measurement procedures will follow manufacturer recommendations.

SAMPLE IDENTIFICATION

Water samples will be identified by unique identification numbers consisting of the station number followed by the date the sample was collected in day-month-year format (e.g., CAM1-040616 for a sample collected from Campbell Creek station CAM1 on April 6, 2016). The containers will be marked with indelible ink and labeled with the following information:

- Sample identification number
- Date and time of collection
- Client name (SIT) and initials of sample collector
- Analytical parameters

Discharge Measurement

Field sampling teams will make discharge measurements at each monitoring location using an Aquacalc Pro and Rickly Hydrologic Price AA current meter system. Discharge measuring procedures will follow the Northwest Indian Fisheries Commission method manual, as described below.

Discharge measurements will be made within the stream channel in an area that best approximates uniform flow and has minimum turbulence. To ensure discharge measurements made in stream channels are consistent from one site visit to the next, field sampling teams will ensure that steel rods are driven into each stream bank to serve as reference points for all subsequent discharge measurements.

To measure discharge, field sampling steams will stretch a surveyor's tape between the steel rods. Channel depth, water depth, and current velocity will then be recorded at each of 10 to 25 intervals along the cross-section (approximately one measurement per 0.5 foot). Velocity will be recorded according to the six-tenths-depth method using a 4-foot wading rod, or a bridge board and 50-pound weight for measurements from bridges. At depths exceeding 2.5 feet, velocity will be measured at two-tenths and eight-tenths depth.

Stream depths measured on the in-stream staff gauge will be read at the beginning and end of each discharge measurement to aid in correcting measurements made during changing conditions, and to facilitate the development of stream discharge rating curves. The sampling team will record velocity and water depth measurements on standardized field forms. Stream discharge will then calculated by multiplying the velocity measurement by the cross-sectional area of each interval and summing the results.

For small streams, velocity measurements will be taken by straddling the channel and inserting the velocity meter into the stream. For larger streams, the measurer will don hip boots or chest waders, and then enter the stream with the velocity meter to make discharge measurements. If high flows create conditions that are too dangerous for the sampling team to enter the stream, discharge measurements will be made by inserting the velocity meter into the stream from an overhanging structure (e.g., a nearby bridge) if possible, or by inserting he velocity meter into the stream from the bank.

Field Sampling Activity Documentation

Field sampling activities will be recorded in a waterproof notebook during the collection of water samples. For all events, station identification, location, sampling time, sampling date, weather, and the sample collector’s name will be recorded. Detailed observational data from each station will recorded including water appearance, biological activity, stream uses, unusual odors, specific sample information, and missing parameters or changes in procedures. Field notes will be scanned and filed following each sampling event.

Field notes will document the following:

- Name and location of project
- Name of field personnel
- Sequences of events
- Changes to plan
- Site and weather conditions
- Number of samples collected
- Number of measurements taken
- Date, time, location, and description of sample
- Results of discharge measurements and gauging equipment
- Comments and unusual circumstances
- Information regarding photo documentation

A chain-of-custody form will accompany each set of samples. The chain-of-custody form indicates the name of the collector of the samples, date and time of collection, number of containers, tests to be performed, shipper, receiver, and date and time of shipping and receiving. Samples are to be placed on ice and delivered to the lab according to procedures pre-arranged with the lab (i.e., delivered on the day of collection or overnight shipment).

LABORATORY PROCEDURES

This section identifies the analytical methods to be used by the laboratory for the SIT long-term monitoring program. This section includes information regarding the procedures for analyzing water samples for parameters of concern and laboratory reporting procedures.

The sample matrix for all samples will be surface water. The required reporting limits of laboratory data should be attainable through the analytical methods listed in Table 5. Laboratory staff will consult with the project manager if any changes in procedures are recommended or if matrix difficulties are encountered. The laboratories will analyze all samples in accordance with standard methods listed in Table 6.

Table 6. Methods and Reporting Limits for Water Quality Analyses.

Parameter	Analytical Method	Method Number	Reporting Limit
Fecal coliform bacteria	Membrane filtration	SM 9222-D	5 CFU/100 mL
Nitrate+nitrite nitrogen	Cadmium reduction	SM 4500NO3I	0.010 mg/L
Turbidity	Nephelometric	SM 2130	1.0 NTU
Suspended sediment	Filtration	ASTM D 3977-97	1.0 mg/L

SM = APHA Standard Methods (APHA 1998).

ASTM = ASTM Method Code (ASTM 2013).

Analytical methods and maximum holding times (see Table 5) meet federal requirements for the Clean Water Act (EPA 2015) and recommendations by Standard Methods (APHA 1998) with the following exception:

- Fecal coliform bacteria will be analyzed within 24 hours of sample collection, exceeding the recommended maximum holding time of 6 hours. Because there are 17 sampling stations, it may not be feasible to deliver all the samples within the 6 hours. Consequently, a holding time of 24 hours will be used for this study.

The quality control objectives established for the fecal coliform membrane filter procedure (Standard Methods method 9222-D in APHA 1998) are to filter a sample volume that yields an ideal range of 20 to 60 fecal coliform positive colonies on a culture plate to obtain statistically reliable results, and for not more than 200 colonies of all bacteria types to be present on a culture plate to ensure that the results are not underestimated due to crowding (e.g., merged colonies or false negatives). The analysis method also provides guidance for calculation of fecal coliform density as follows:

- If one of the plate counts is between 20 and 60, then calculate the density for the sample volume yielding a plate count in this ideal range.

- If duplicate sample volumes were analyzed then calculate the average density for both analyses.

- If all counts are outside the ideal range then calculate the average density for all sample volumes analyzed, excluding counts greater than 200, by dividing the sum of the plate counts by the sum of the sample volumes.

- If no plate counts less than 200 are obtained, but a plate has a total bacterial colony count greater than 200, then report the density as greater than the value associated with this plate count.

Laboratory Data Reports

Data reports from the laboratories will present the test results clearly and accurately. The test report will include the information necessary for interpretation and validation of the data. Data reports will be submitted as hard and electronic (Excel spreadsheets) copies, and will include the following:

- Report title
- Name and address of laboratory
- Name and address of client and project name
- Description and unambiguous name of tested sample
- Date and time of sample collection, date of sample receipt, and date of analysis
- Identification of test method
- Quality control results for laboratory spikes and percent recovery of spiked samples (nutrient samples only)
- Quality control results for laboratory duplicates and relative percent difference of laboratory duplicates
- An explanation of failed quality control and any non-standard conditions that may have affected the data quality
- Microbial Worksheet containing plate count data for each dilution of fecal coliform bacteria samples, and results of positive and negative controls
- Completed chain-of-custody record
- A signature and title of laboratory director or designee

Electronic Data

Field and laboratory data for this monitoring study will be entered into an Excel spreadsheet for all subsequent data management and archiving tasks. The SIT project manager will perform an independent review to ensure that all the data were entered without error (see the *Audits and Reports* section).

QUALITY CONTROL

To ensure the data quality objectives for this study are met, the project team will implement the procedures specified in the following subsections for field and laboratory quality control.

FIELD QUALITY CONTROL PROCEDURES

Quality control procedures used for field activities are described in the following sections. The frequency and type of quality control samples to be collected in the field are summarized in Table 7.

Table 7. Quality Control Samples for Each Parameter.

Parameter	Method Blank	Matrix Spike	Control Sample	Lab Duplicate	Field Duplicate
Fecal coliform	1 per event	NA	NA	1 per event	1 per event
Nitrate+nitrite nitrogen	1 per event	1 per event	1 per event	1 per event	1 per year
Turbidity	1 per event	NA	1 per event	1 per event	1 per year
Suspended sediment	2 per event	NA	NA	NA	1 per year

NA = not applicable

Field Logbooks and Data Forms

The sampler will document sampling event observations in a waterproof field notebook. Documentation will be sufficient to enable participants to accurately and objectively reconstruct events that occurred during the project at a later time. Entries will be made in waterproof ink, dated, and signed. If corrections are necessary, they will be made by drawing a single line through the original entry (so that the original entry is legible) and writing the corrected entry alongside. The correction will be initialed and dated. Corrected errors may require a footnote explaining the correction.

Custody Procedures

The primary objective of chain-of-custody procedures is to provide an accurate written or computerized record that can be used to trace the possession and handling of a sample from collection to completion of all required analyses. A sample is in custody when any of the following conditions are true:

- The sample is in someone's physical possession
- The sample is in someone's view
- The sample is locked up
- The sample is kept in a secured area that is restricted to authorized personnel

Field Custody Procedures

The sampler will use the following guidance to ensure proper control of samples while in the field:

- As few people as possible will handle the samples.
- The Field Sampler will be responsible for the care and custody of collected samples until they are transferred to another person or dispatched properly under chain-of-custody rules.
- The Field Sampler will determine whether proper custody procedures were followed during the fieldwork and will decide if additional samples are required.

The Field Sampler will be responsible for packaging and delivering samples to the laboratory. The container in which samples are packed will be accompanied by one copy of the chain-of-custody record. When transferring samples, the individuals relinquishing and receiving them must sign, date, and note the time on the chain-of-custody record. This record will document sample custody transfer. Samples will be delivered to the laboratory for analysis with separate chain-of-custody records accompanying each sampling event.

Laboratory Custody Procedures

A designated sample custodian at the laboratory will accept custody of the samples from the delivery person and enter preliminary information about the package into a package or sample receipt log, including the initials of the person delivering the package. The custodian responsible for sample log-in will follow the laboratory's SOP for opening the package, checking the contents, and verifying that the information on the chain-of-custody agrees with samples received. The laboratory will follow its internal chain-of-custody procedures as stated in the laboratory quality assurance manual.

LABORATORY QUALITY CONTROL PROCEDURES

Laboratory quality control samples are summarized in Table 7. The laboratory will analyze all the samples collected during each event in a single batch. By doing this, a single set of quality control parameters will be applicable to all samples collected during each sampling event.

A method blank will be analyzed with each batch to assess potential contamination from sample handling in the laboratory.

The laboratory control sample (LCS) is sometimes referred to as a blank spike. The LCS is used to measure the accuracy of the laboratory by determining the ability of the lab to recover known amounts of target analytes in the absence of matrix effects.

Laboratory duplicates are analyzed from separate aliquots of one sample. Analytical precision is evaluated by the relative percent difference between the laboratory duplicates.

LCS tests are not required for SSC. Laboratory blanks and laboratory duplicate analyses provide sufficient quality control data to meet the data quality objectives for this project.

DATA MANAGEMENT PROCEDURES

The following section describes the procedures that will be used to ensure that all data generated for the SIT long-term monitoring program are accurately entered into the project database, are securely stored in a manner that facilitates data analysis, and are properly archived. This section includes the following elements:

- Data path
- Record-keeping and data storage
- Forms and checklists
- Data handling
- Hardware and software requirements

DATA PATH

Samples will be collected and transferred to the laboratory for analysis as described above. Data will be sent by the analytical laboratory to the SIT project manager in an electronic format within 30 days of receiving the samples for analysis. SIT staff will transmit the laboratory data and report along with the field notes to the Quality Assurance Officer, who will then review the data and complete a Data Quality Assurance Worksheet. The worksheet and the approved data will be submitted to the SIT project Manager. Field and laboratory data will be entered into a project database described below, including the corrections and data flags specified in the Data Quality Assurance Worksheet, and submitted with the Project Report.

Continuous hydrologic and water quality data from each monitoring station will be imported directly into a spreadsheet database for subsequent analysis and archiving purposes. These data will be immediately checked for evidence of an equipment malfunction or other operational problems. Continuous hydrologic and water quality will be managed in spreadsheets with one row for each observation or measurement. Gaps in continuous data may need to be interpolated; if this occurs, data will be stored and presented in a manner that makes it clear which data are from measurements, and which have been interpolated.

RECORD-KEEPING AND DATA STORAGE

Original field notebooks, field datasheets, and laboratory data sheets will be stored at the SIT Natural Resources Office for a 5-year period after sample collection. The project database will be located on a network server at the SIT Natural Resource office and backed up on a regular basis.

FORMS AND CHECKLISTS

Standardized forms will not be used on this project with the exception of a chain-of-custody form provided by the analytical laboratory.

DATA HANDLING

All field and laboratory monitoring data will be entered into an Excel spreadsheet for subsequent data management and archiving tasks. Laboratory data for each analytical batch will be combined into one spreadsheet with one row for each sample, which allows for sorting and statistical analyses. Continuous hydrologic and water quality data will also be combined into spreadsheets with one row for each observation or measurement. Gaps in continuous data may need to be interpolated; if this occurs, data will be stored and presented in a manner that makes it clear which data are from measurements, and which have been interpolated.

The SIT project manager will perform an independent review to ensure that all the data have been entered without error.

HARDWARE AND SOFTWARE REQUIREMENTS

Software required for the data management and analysis tasks related to this project will include but not be limited to Microsoft® Excel. Commensurate with these software requirements, the minimum hardware requirement for this project is a Windows® 7 compatible personal computer operating in a networked environment.

AUDITS AND REPORTS

The following section describes the procedures used to ensure that this QAPP is implemented correctly and that the data generated is of sufficient quality to meet the project objectives, and that corrective actions, if necessary, are implemented in a timely manner. The procedures include audits and response actions; deficiencies, nonconformances, and corrective actions; and reports to management.

AUDITS AND RESPONSE ACTIONS

Audits will be conducted for field, laboratory, and data management activities, following the schedule outlined below in Table 8.

Table 8. Quality Assurance Audit Schedule and Response Actions.				
Assessment Activity	**Approximate Schedule**	**Responsible Party**	**Scope**	**Response Requirements**
Field Measurement Audit	Within 60 days of completion of sampling event	SIT Project Manager	Review of field notes, discharge measurement, and flow data	Annotate field notes and notify field staff within 3 days
Laboratory Measurement Audit	Within 60 days of receiving laboratory data reports	SIT Quality Assurance Officer	Review analytical and quality control procedures employed at laboratory	Laboratory to respond in writing within 3 days to address corrective actions
Data Entry Audit	Within 60 days of data entry	SIT Data Manager	Review all data entry values	Correct errors and repeat audit until no errors found

Deficiencies, Nonconformances, and Corrective Action

The Project Manager is responsible for implementing and tracking corrective action procedures as a result of audit findings by the Data Quality Assurance Officer. Records of audit findings and corrective actions are maintained by the Data Quality Assurance Officer in the project file. Documentation of quality assurance issues will be made by the Data Quality Assurance Officer in the project file and in quality assurance worksheets, if applicable.

Upon completion of an audit, the results will be reviewed to determine if a deficiency has occurred, and whether the deficiency is classified as a nonconformance. Deficiencies are defined as unauthorized deviations from procedures documented in the QAPP. Nonconformances are deficiencies which affect data quality and render the data unacceptable or indeterminate. Deficiencies related to field and laboratory measurement systems include, but are not limited to, instrument malfunctions and quality control sample failures.

The Project Manager, in consultation with the Data Quality Assurance Officer (and other affected individuals or organizations), will determine if the deficiency constitutes a nonconformance. If it is determined a nonconformance does exist, the Project Manager, in consultation with the Quality Assurance Officer, will determine the disposition of the nonconforming data or activity and necessary corrective action(s). Corrective actions may include the qualification of the data as estimates (J) or rejected (R). If the data is qualified as rejected (R), additional corrective actions may include collection of additional samples or reanalysis of the existing samples as authorized by the Project Manager.

Reports to Management

A project report will be prepared at the end of each year to present the collected data and summarize the study findings. This report will identify the specific goals of the monitoring program and then describe the monitoring procedures that were implemented to achieve those goals. Data quality assurance objectives and review findings will be summarized. Results of the monitoring program will then be presented and evaluated using supporting graphical and/or tabular representations of the data as necessary. Results from statistical analyses that are performed on the data will also be presented and discussed in detail. Finally, major conclusions from the monitoring program will be presented at the end of the report.

All validated project data will be entered into a spreadsheet database (Excel) that will be suitable for data analysis and preparation for submittal to environmental databases (e.g., EPA STORET, Ecology EIM). The quality assurance officer will perform an independent review of all data entry to ensure individual sample values and data flags were entered without error. The project database will be included as an appendix to the summary report.

DATA VERIFICATION AND VALIDATION

This section defines data review, verification, and validation and then presents the methods to be used to verify and validate the data, including the procedures that will be followed if MQOs are not met.

DATA REVIEW, VERIFICATION, AND VALIDATION

For the purposes of this document, data verification is a systematic process for evaluating performance and compliance of a set of data to ascertain its completeness, correctness, and consistency using the methods and criteria defined in the QAPP. Validation means those processes taken independently of the data-generation processes to evaluate the technical usability of the verified data with respect to the planned objectives or intention of the project. Additionally, validation can provide a level of overall confidence in the reporting of the data based on the methods used.

All data obtained from field and laboratory measurements will be reviewed and verified for conformance to project requirements, and then validated against the data quality objectives which are listed in the *Quality Objectives* section. Only those data which are supported by appropriate quality control data and meet the measurement performance specification defined for this project will be considered acceptable and used in the project.

The Field Sampler is responsible for ensuring that field data are properly reviewed and verified for integrity. The Laboratory Manager is responsible for ensuring that laboratory data are scientifically valid, defensible, of acceptable precision and accuracy, and reviewed for integrity. The Quality Assurance Officer is responsible for validating the data. The Data Manager is responsible for entering the data in the project database. The Project Manager will be responsible for ensuring that all data are properly reviewed and verified, and submitted in the required format to the project database. Finally, the Project Manager, with the concurrence of the Quality Assurance Officer, is responsible for ensuring that all data to be reported meet the objectives of the project and are suitable for reporting.

VERIFICATION AND VALIDATION METHODS

All data will be verified to ensure they are representative of the samples analyzed and locations where measurements were made, and that the data and associated quality control data conform to project specifications. The staff and management of the respective field, laboratory, and data management tasks are responsible for the integrity, validation, and verification of the data each task generates or handles throughout each process. The field and laboratory tasks ensure the verification of raw data, electronically generated data, and data on chain-of-custody forms and hard copy output from instruments. This section presents the data verification and validation procedures for laboratory data.

Laboratory data will be verified and validated within 14 days of receiving the results from the laboratory. This review will be performed to ensure that all data are consistent, correct, and complete, and that all required quality control information has been provided. Quality control reviews, and any problems and corrective actions, will be summarized in a Quality Assurance Worksheet. Values associated with minor quality control problems will be considered estimates and assigned *J* qualifiers. Values associated with major quality control problems will be rejected and qualified *R*. Estimated values may be used for evaluation purposes, whereas rejected values will not be used. The following sections describe the data validation procedures for these quality control elements:

- Completeness
- Methodology
- Holding times
- Blanks
- Control Standards
- Matrix spikes
- Laboratory duplicates
- Field duplicates
- Fecal coliform bacteria enumeration

Completeness

Completeness will be assessed by comparing valid sample data with this quality assurance project plan and the chain-of-custody records. Completeness will be calculated by dividing the number of valid values by the total number of values. Samples will be reanalyzed or recollected if completeness is less than 95 percent.

Methodology

Methodology will be assessed by examination of the field notebook and laboratory reports for any deviations from this sampling and analysis plan. Unacceptable deviations will result in rejected values (R) and will be corrected for future analyses.

Holding Times

Analysis dates and times will be reported by the laboratory. Maximum holding times will be assessed by comparing analytical dates to sample collection. Values that exceed the maximum holding time (e.g., 24 hours for fecal coliform bacteria) will be considered estimates (J), whereas severe exceedances (e.g., greater than 48 hours for fecal coliform bacteria) may result in rejected values (R).

Blanks

One preparation blank consisting of clean laboratory water will be analyzed with each sample batch, and the results will be reported in each laboratory report. Sample values that are less than 5 times a detected blank value will be considered estimates (J).

Control Samples

Control samples are analyzed with each batch of samples. Percent recovery values that exceed the quality control objectives will be noted in the quality assurance worksheets, and associated values will be flagged as estimates (J). If the objectives are severely exceeded (e.g., less than 10 percent recovery), then the associated values may be rejected (R).

Matrix Spikes

Matrix spike samples are analyzed with each batch of samples. Percent recovery values that exceed the quality control objectives will be noted in the quality assurance worksheets, and associated values may be flagged as estimates (J). If the objectives are severely exceeded (e.g., less than 10 percent recovery), then the associated values may be rejected (R). Data other than the original sample will not be flagged for only matrix spike exceedances.

Laboratory Duplicates

Precision of laboratory duplicate results will be presented in each laboratory report. One laboratory duplicate will be analyzed with each batch of samples. In this case, a batch represents the samples collected during one sampling event.

Two levels of precision for duplicate analyses will be evaluated using reported values. The RPD of laboratory duplicates will be less than or equal to 20 percent (35 percent for fecal coliform) for values that are greater than 5 times the reporting limit, and ± 2 times the reporting limit for values less than or equal to 5 times the reporting limit. Results exceeding the quality control objectives will be noted in the quality assurance worksheets, and associated values will be flagged as estimates (J). If the objectives are severely exceeded (e.g., more than twice the objective), then the associated values may be rejected (R).

Fecal Coliform Bacteria Enumeration

Raw data for all fecal coliform bacteria analyses will be reviewed to evaluate whether the plate counts were properly used to calculate the results and the quality control objectives established by the method were met (see Measurement Procedures). Fecal coliform bacteria results for this project will be qualified as estimates (J) if the plate count is outside the ideal range of 20 to 60 colonies, and will be qualified as greater than (>) if the plate count exceeds 200 colonies and is reported as too numerous to count (TNTC).

DATA QUALITY (USABILITY) ASSESSMENT

Procedures that will be used to assess the usability of the data and then analyze the data are described in the following sections.

DATA USABILITY ASSESSMENT

The Project Manager will review the compiled quality assurance data for water quality and flow monitoring, respectively, using the MQOs that have been identified in this QAPP. Review results will be presented in the project report by summarizing quality control results, identifying when data quality objectives were not met, and discussing the resulting limitations (if any) on the use or interpretation of the data. Specific quality assurance information that will be noted in the data quality assessment section of the report includes the following:

- Changes in and deviations from the monitoring and quality assurance plan
- Results of performance and/or system audits
- Significant quality assurance problems and recommended solutions
- Data quality assessment results in terms of precision, bias, representativeness, completeness, comparability, and reporting limits
- Discussion of whether the quality assurance objectives were met and the resulting impact on decision-making
- Limitations on use of the measurement data

DATA ANALYSIS PROCEDURES

The project team will perform the following analyses and computations using the data compiled through the monitoring activities described above:

- Calculate summary statistics (see below) for temperature, pH, conductivity, dissolved oxygen, and fecal coliform bacteria concentrations for each monitoring station by season (i.e., summer and winter). The specific summary statistics that will be calculated for each subset of data will include: median, mean (geometric for fecal coliform bacteria), minimum, maximum, 25th percentile, 75th percentile, and 90th percentile (bacteria only). These calculations will be straightforward because few if any non-detect values are anticipated. One-half the detection limit will be used for non-detect values.

- Compare the geometric mean and 90th percentile of fecal coliform bacteria concentrations for each season (summer and winter) to Washington State water quality criteria.

- Perform temporal trend analysis using a non-parametric statistical test (e.g., Seasonal Mann Kendall) on discrete data for fecal coliform bacteria and water quality field parameters, and on continuous flow and temperature data to determine whether there is a statistically significant shift in those parameters over time.

- Perform spatial trend analysis using a non-parametric statistical test (e.g., Freidman test followed by a multiple range test) to determine whether there is a statistically significant difference between monitoring stations for each parameter.

- Perform regression analysis of turbidity and SSC data, and apply model representing the relationship between SSC and turbidity to the continuous turbidity record to produce a continuous record of SSC data at station CRA0 (or where the turbidity meter is deployed in the future).

- Compute monthly and seasonal loading rates for nitrate and suspended solids concentration at station CRA0 (or where the turbidity meter is deployed in the future).

Statistical significance of trends and the correlation coefficients will be evaluated based on an alpha-level of 0.05 using methods by Helsel and Hirsch (1992).

Data from the continuous flow monitoring will be processed to calculate the following indicators for evaluating hydrologic impacts from urban development and climate change as described in DeGasperi et al. (2009):

- **High pulse count**: occurrence of daily average flows that are equal to or greater than a threshold set at twice (2 times) the long-term daily average flow rate.

- **High pulse frequency**: number of days each water year that discrete high flow pulses occur.

- **High pulse count duration**: annual average duration of high flow pulses during a water year.

- **High pulse count range**: range in days between the start of the first high flow pulse and the end of the last high flow pulse during a water year.

- **Low pulse count**: occurrence of daily average flows that are equal to or less than a threshold set at 50 percent of the long-term daily average flow rate.

- **Low pulse count frequency**: number of times each calendar year that discrete low flow pulses occurred.

- **Low pulse count duration**: annual average duration of low flow pulses during a calendar year.

- **Low pulse count range**: range in days between the start of the first low flow pulse and the end of the last low flow pulse during a calendar year.

- **Low flow frequency statistics:** 7 and 30 consecutive-day low flow rates with recurrence intervals of 2 and 10 years.

- **Richards-Baker (RB) flashiness index**: a dimensionless index of flow oscillations relative to total flow based on daily average discharge measured during a water year.

- **TQ Mean**: the fraction of a year that mean daily discharge exceeds annual mean discharge.

- **Total flow volume**: total discharge volume over a water year.

Trends over time at each monitoring station will be evaluated using parametric (Pearson's r) and nonparametric (Kendall's tau or Spearman's rho) tests of correlation between these indicators and time. Statistical significance of the correlation coefficients will be evaluated based on an alpha-level of 0.05 for a two-tailed test.

The project team will calculate absolute and unit area loading rates for nitrate and suspended sediment measured at the one water quality monitoring station with continuous measurements of flow, nitrate, and suspended sediment (calculated from turbidity). Pollutant loading rates will be calculated as the product of flow times concentration, and summed by day, month, season, and year.

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APPENDIX A

Squaxin Island Tribe Water Quality Monitoring Narrative

Squaxin Island Tribe Water Quality Monitoring Narrative
Summarized by Erica Marbet for Herrera Environmental
August 19, 2015

Contents

In the two years that I have been with Squaxin Natural Resources, this is what I can piece together as the body of the water resources program.

Objectives and Basis

The Squaxin Island Tribe is a true leader in management of natural resources thanks to countless years of traditional knowledge. Our steady leadership has helped form logical solutions for a wide range of issues both on local and regional levels. The natural resources department works to carry out the Tribe's strong conservation ethic and principles for salmon recovery and shellfish enhancement in South Salish Sea (South Puget Sound) commensurate with Treaty obligations. The Squaxin Island Tribe has co-management responsibilities with the State of Washington for these natural resources. That responsibility includes ensuring the requisite environmental quality necessary to sustain them, consistent with the Treaty and federal court rulings of, "abundant fish and shellfish safe to harvest and eat." However, the current condition of natural resources in South Salish Sea falls far short of our expectations and government obligations. In order to counter and remedy these shortcomings, the natural resource department has developed a framework consisting of goals, fundable initiatives (contained in a nonpoint source pollution plan), and special policy initiatives. Central to the effort is long term monitoring of water quality and quantity. We generally do this work with EPA grants: the Performance Partnership Grant, and some National Estuarine Program funding (through WA Dept. of Health and Mason County). We have recently received BIA funding to explore assess the potential effects of climate change on the Tribe's resources.

Clean Water Act Section 106 and 319

Partial funding for salaries and $8000 annually for lab samples. $10,000 annually to USGS to maintain the Goldsborough Creek gaging station.

We receive EPA Clean Water Act, Section 106 and 319 funding through a Performance Partnership Grant, which we use to:

- Collect regular long-term measurements of water quality parameters that are indicators of ecological health. Focus on freshwater streams that drain to the South Sound. Examples: Temperature, dissolved oxygen, pH, conductivity, nitrogen and phosphorus concentration, and fecal coliform bacterial counts. Our longest data sets and most extensive records are for:
  - Fecal Coliform- Monthly by grab sample.
  - Temperature- Hourly, continuous deployment of thermistors.
  - Dissolved Oxygen/pH/Conductivity/Salinity-Monthly with a water quality sonde.

We have a lot of opportunistic measurements of a variety of parameters, but they are not consistent.

- Maintain multiple gaging stations and develop long-term records of streamflow in the South Sound. Develop long-term records of water level in select lakes and wetlands. Water quality and quantity are linked. *Land use and development change streamflow regimes, and it is only possible to detect these changes by building long term records.*

  - Stage- Fifteen-minute continuous deployment of pressure transducers
  - Discharge- Monthly measurement with flow meter. Rating development for estimate of fifteen-minute discharge values.
  - Water level- Hourly continuous deployment of pressure transducer at Mason Lake only. This is a recent addition, continuing on with a ten-year daily record that was collected by a local resident at his dock.
- Conduct regular long-term plankton monitoring around Squaxin Island. Monthly in the winter and weekly in the summer. Current application: early detection of harmful algal blooms.

National Estuarine Program Funding: Fecal Coliform Bacteria
Past $20-50,000 annually for salary and lab fees will end this calendar year.

Performance Partnership Grant funds alone are insufficient to cover all of the Tribe's water monitoring. Likewise in Mason County, cutbacks in funding for Public Health Department led to a reorganization of fecal coliform bacteria monitoring efforts at the end of 2008. Mason County and the Squaxin Island Tribe completely eliminated any duplication of effort. This partnership received additional funding from WA State Department of Health in the form of a National Estuarine Program Pollution Inventory and Correction ("PIC") grant. Squaxin is the only government with the capacity to conduct the early warning system bacterial monitoring of freshwater parallel to the Department of Health marine water quality monitoring program. The data is provided to Mason County at least twice a year. Without Squaxin participation, there will be no implementation of management measures to bacterial pollutant loadings and sustain the opportunity to harvest shellfish. ***PIC funding is expected to run out at the end of 2016.***

BIA Climate Change Funding:
$10,000 for Herrera water quality monitoring plan development
*Occasional flexibility in purchasing some monitoring equipment in the range of a few thousand dollars. *
Future opportunities to request funds.

Any environmental monitoring that has been established by the Tribe is now relevant to a new focus on climate change. The South Sound is influenced primarily by the rest of the Sound and by the Pacific Ocean. Secondary influence is from all freshwater tributaries, which is seasonably variable. The physical, chemical, and biological balance of the South Sound is shifting and changing. Our ability to discern the effects of climate change from other human impacts, and to understand their ultimate effect on the Tribe's resources, will guide the actions that must be taken by the Tribe to preserve their traditions and future prosperity. A simple example is the temperature of the South Sound. A more complicated example is nitrogen concentration, which drives primary productivity, oxygen and carbon dioxide levels, and the pH of the South Sound. Temperature and pH both greatly affect finfish and shellfish.

Elements

Multiple large and small scale maps are provided in Appendix 1 for use while reading below.

Database- Microsoft SQL 2012- Tribal Water Quality Database- Northwest Indian Fisheries Commission created the database and provides support. All fecal coliform data are uploaded. We need to add SUNA and streamflow measurements. We need to update temperature and sonde measurements.

Water Quantity- (Table 1, Figure 1)- Monthly Discharge
Continuous 15-min Stage

Seven gaging stations and a variety of opportunistic flow calculations.
We use Solinst pressure leveloggers to measure stage. We use Aquacalc handhelds with pygmy and Price AA flow meters to calculate discharge. Our rating curve software is Aquarius. This software also has a database function.

We fund the USGS to maintain the Goldsborough Creek gage, $10,000 per year.

Various groundwater- water table measurements. These were taken in the past. I know little about them.

Water Quality- (Table 2), Appendix 2 Monthly

Sonde Measurements- The department had some kind of sonde from 2003 to 2010 and took a variety of measurements at many sites, though the measurements were not consistently monthly or annual over the years. At this point we have consistent monthly sonde measurements starting in about January 2013, though these recent measurements are not yet in the database. Current sonde is a YSI 6920 V2. Parameters include: Temperature, Conductivity, Salinity, pH, Chlorophyll
Dissolved Oxygen.

*Temperature Thermisters***- (**Table 2**,** Figure 2**)** Continuous 15-min

Thermisters have been installed at these streams: Burley, Coulter, Cranberry, Goldsborough, Huge, Johns 1, Johns 2, Mclane, Mill, Sherwood, Skookum, Woodland. These are the site of the Tribe's streamflow gaging stations, with the exception of Burley, Huge, Mclane, Goldsborough, and Woodland. Those are gaged by other entities. We started monitoring in 2006; only 2006 to 2009 are in the database. We use Onset Hobo Pro V2 temperature loggers.

One of our biologists measures the temperature of Puget Sound at the Tribe's net pens, located between Squaxin Island and Harstine Island.

Grab Samples: (Table 2), Appendix 2 Monthly Fecal Coliform
Annual Nitrogen and Total Suspended Sediment

The Tribe began consistent monthly fecal coliform sampling in 2004. Also, in beginning in 2013, a total suspended sediment and nitrate-nitrite sample are taken annually, in the fall, at each long term site. All of these data are uploaded to the database through December 2014. Otherwise there seem to have been a few rounds of opportunistic sampling over the years, so we have background samples of ammonia, nitrogen, phosphorus, and turbidity.

Mason County does ambient and targeted sampling of fecal coliform in freshwater and along Puget Sound shorelines.

Washington Department of Health has fecal coliform sampling stations in Puget Sound.

SUNA Nitrate Meter *Weekly at Johns and Spurgeon Creek*

This is a recent addition to our water quality monitoring program, which we put into use in the past year. We used it to collect some nitrate data at Johns Creek, on the Bayshore Golf Course. Currently we are collecting weekly measurements at Johns Creek and also Spurgeon Creek in Thurston County. There is no objective for doing so.

Plankton Sampling *Monthly to Weekly*

Samples taken from points around Squaxin Island weekly in the summer. Monthly sample taken from Collier Dock. Objective is primarily to look for harmful algae, but we have the opportunity to expand this to inventory of plankton community.

Personnel

1 Water Resources Biologist
1 Water Resources Technician
1 GIS Specialist whose services are used by many departments in the Tribe.
1 Climate Change Scientist who is partially available.
We receive assistance and spend time assisting all personnel in the Natural Resources Department.

Opportunities for Change-

Cease total suspended sediment samples. Purchase a turbidity sensor.

Determine if other entities collect temperature data at the sites where they gage streamflow.

Put the SUNA to use at our long term sites or for deployments at specific sites. Use more continuous monitoring with flow data to calculate nitrogen loading.

We will look to fund specific pieces of equipment with targeted grants in the future.

We have not yet calculated fecal coliform loading to the site where we measure streamflow. This is would be an essential part of understanding bacterial loading to South Sound.

Broaden fecal coliform sample sites to include some upstream “background” sites by cutting back sampling at other sites for only one sample a year.

Table 1. Squaxin Island Tribe long-term gaging stations. USGS now maintains Goldsborough Creek station.

Site	Watershed Area (acres)	2011-2012 Mean Annual Flow (afy)	2011-2012 Mean Annual Flow (cfs)	2011-2012 Sanderson Field Total Annual Precip. (inches)	**Full Record Sanderson Field Mean Annual Precip. (inches)**	2011-2012 Min. Daily Flow (cfs)	2011-2012 Max Daily Flow (cfs)	2011-2012 7-day Low Flow (cfs)	**Full Record Mean Annual Flow (cfs)**	Location	First Water Year
Coulter	8960	23653	32.6	62.7	**66.7**	12.9	*281*	13.4	**12.0**	Just up from North Bay Road, near mouth of creek.	2005-2006
Cranberry	7680	28743	39.6	62.7	**66.7**	5.1	*298*	5.4	**5.7**	At Hwy. 3	2003-2004
Johns 1	10240	28793	39.7	62.7	**66.7**	6.9	130	8.0	**34.5**	At Hwy. 3	2005-2006
Johns 2	8320	20827	28.7	62.7	**66.7**	5.2	*105*	4.7	**5.9**	At Johns Creek Road	2003-2004
Mill	12160	50829	70.0	62.7	**66.7**	9.9	*357*	10.6	**3.8**	At Hwy. 3	2003-2004
Sherwood	20480	45930	63.3	62.7	**66.7**	9.4	*479*	9.6	**10.2**	Below major confluence at E. Sherwood Creek Road	2006-2007
Skookum	12800	44018	60.6	62.7	**66.7**	2.2	737	2.5	**7.9**	At Hwy. 101	2004-2005
Goldsborough	37760	109900	151	62.7	**66.7**	36	783	36	**2**	USGS gage, the Tribe measured the first few years though.	2004-2005

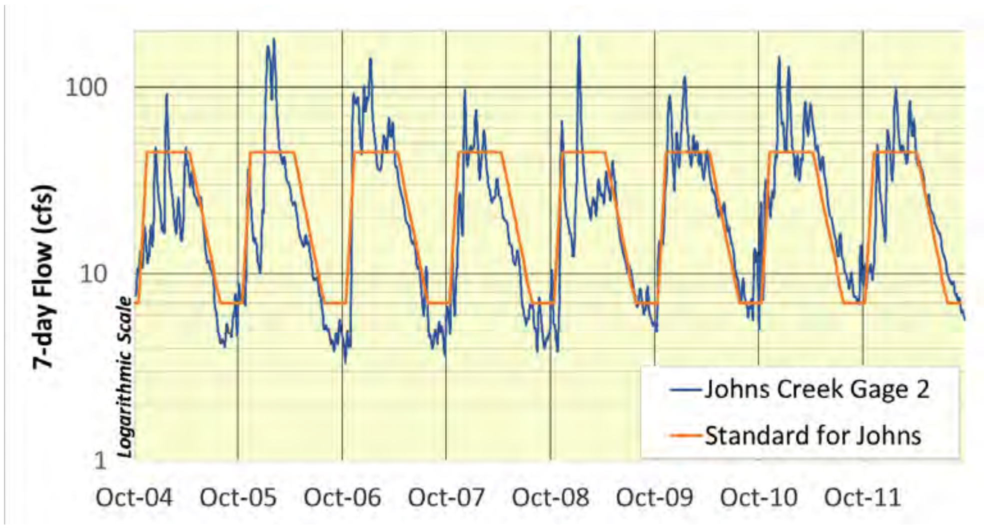


Figure 1. Example of stream gaging data: 7-day running mean of the minimum daily flow at Johns Creek 2.

Table 2. Water quality and temperature monitoring sites for the Squaxin Island Tribe.

Code	Stream	Fecal Sampling Start Date	Temperature station?*	Gaging Station?	Comment
CAM1	Campbell 1	2005			
COU1	Coulter 1	2012	Yes	At COU1	Picked up this site in 2013 for monthly fecal coliform and annual nitrogen, phosphorus.
CRA0	Cranberry 0	2004			Moved Cranberry sample site from CRA1 to CRA0, inside the Twin River Ranch in summer 2006.
CRA1	Cranberry 1	2004	Yes	at CRA 1	Collected data here and at CRA0 until 2012, when we switched to primarily CRA0.
DEE0	Deer 0	2004			
GOL0	Goldsborough 0	2004	Yes	USGS at GOL2	
HUR1	Hurley 1	2006			
JOH0	Johns 0	2004		At JOH1 and JOH2	Monthly measurments of Nitrogen, total suspended solids were started at this site in January 2013, one year prior to the closure of the Bayshore Golf Course.
JOH1	Johns 1	2004	Yes	At JOH1 and JOH2	This was originally, the site for monthly fecal coliform measurments, but we switched to sampling downstream at JOH0 in January 2013, one year prior to the closure of the Bayshore Golf Course.
LIT1	Little 1	2006			
MAL1	Malaney 1	2004			
MIL0	Mill 1	2004	Yes at MIL3	At MIL3	
ROC1	Rocky 1	2012			Decided in 2012 to put this site in the long-term group.
SHE1	Shelton 1	2004			
SHR1	Sherwood 1	2012	Yes	At SHR1	Decided in 2012 to put this site in the long-term group.
SKO0	Skookum 0	2006			
SKO3	Skookum 3	2006	Yes	At SKO1	
TR24	Twin Rivers 24	2006			
UNC02	Uncle Johns 2	2004			
UNC00	Juncle Johns 0	2004			
*Additional temperature stations at: Burley, Huge, Mclane, and Woodland Creek.					

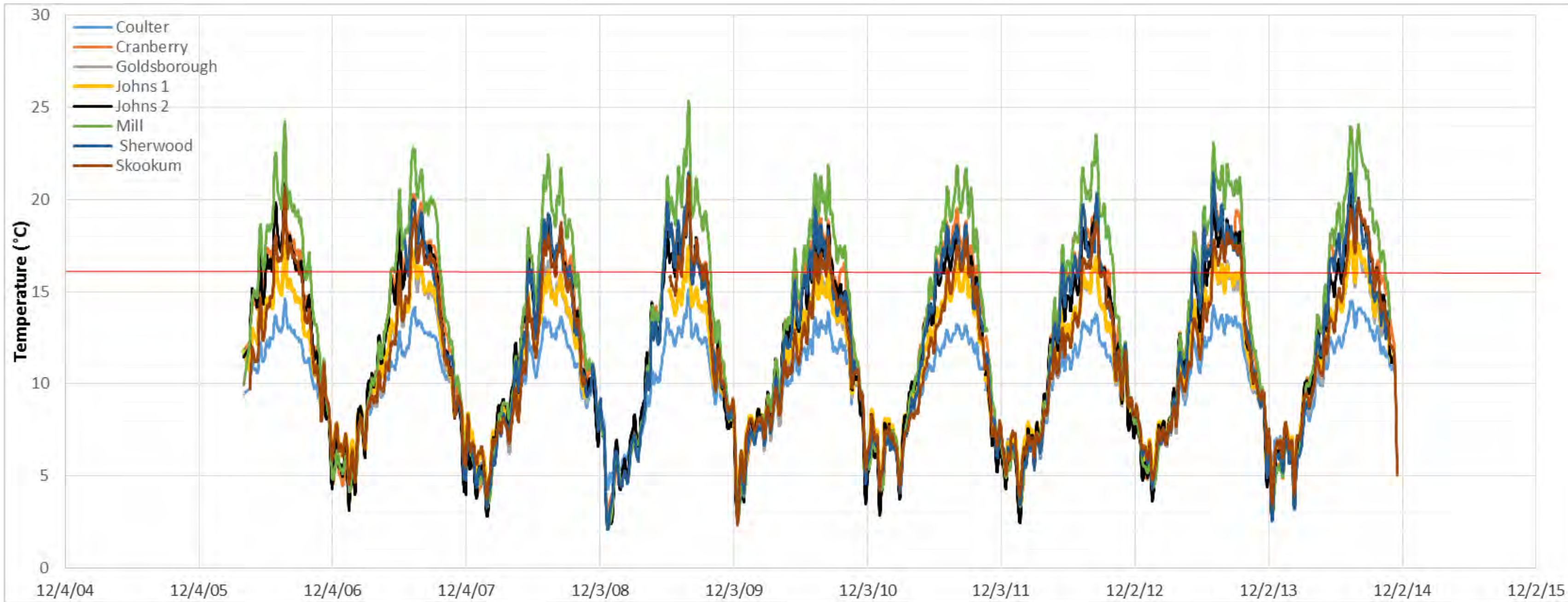
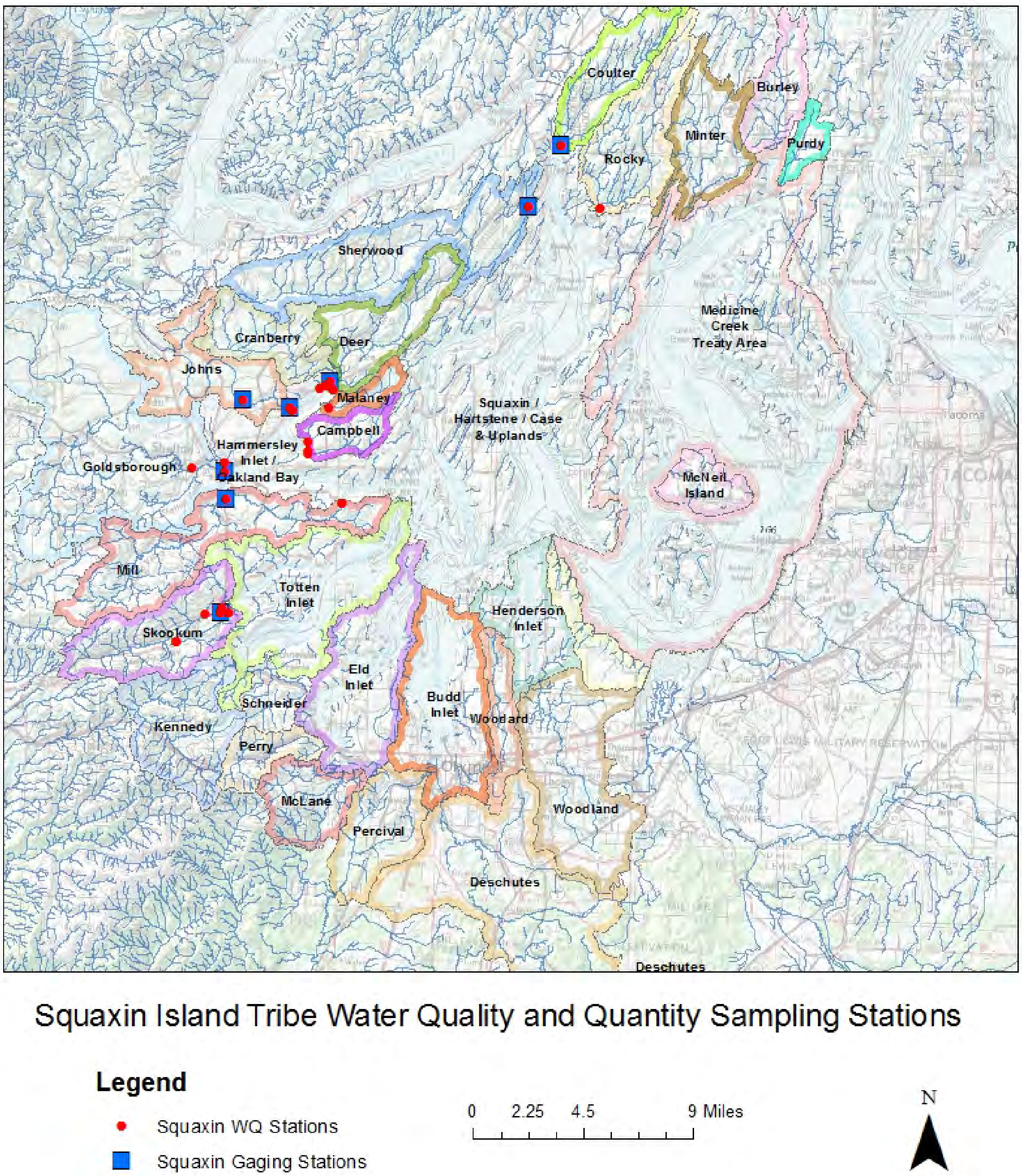
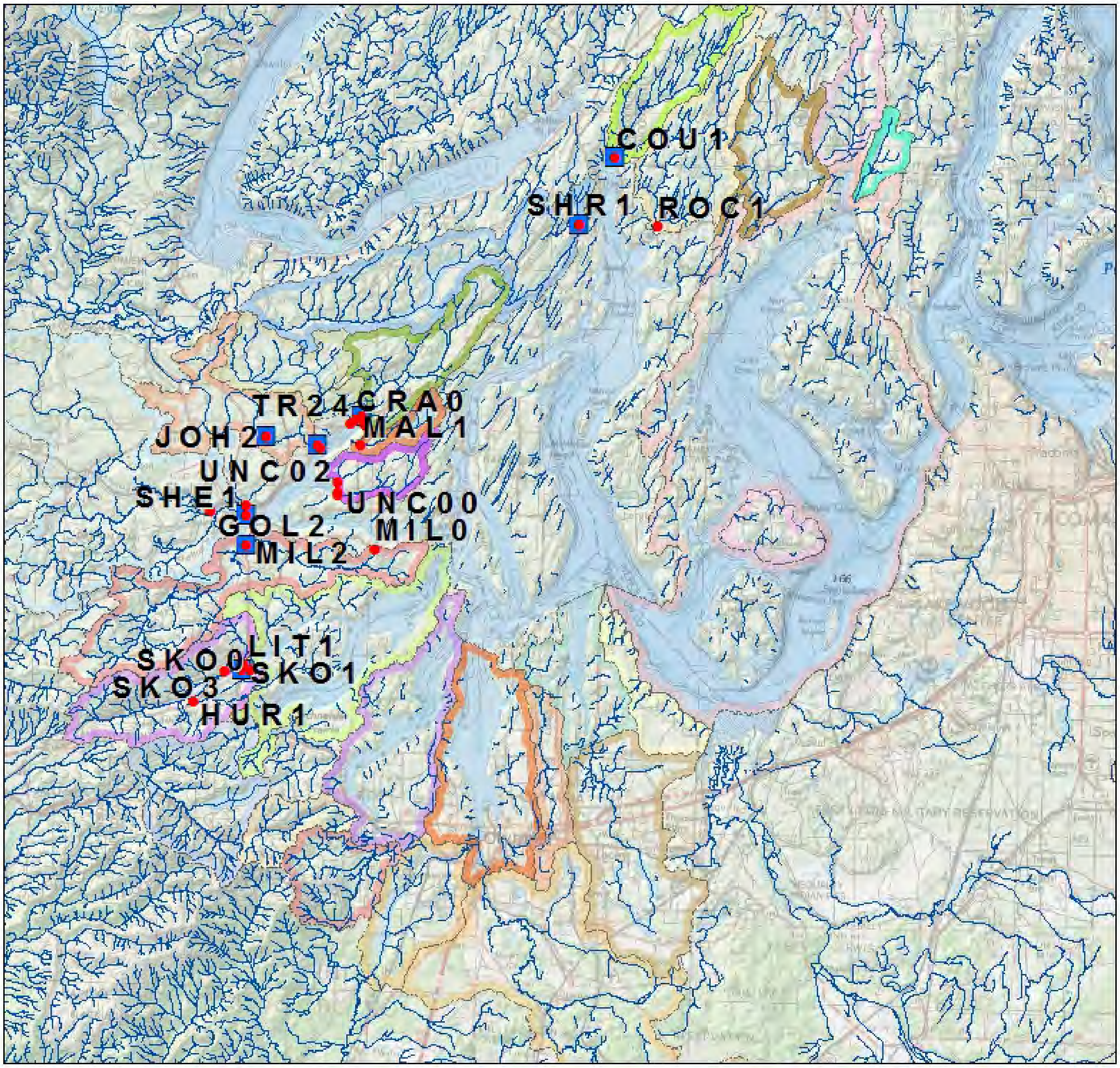


Figure 2. Example of stream temperature data: Seven-day running mean of the maximum daily temperature.

Appendix 1. Maps of Water Quality Sampling Stations of the Squaxin Island Tribe





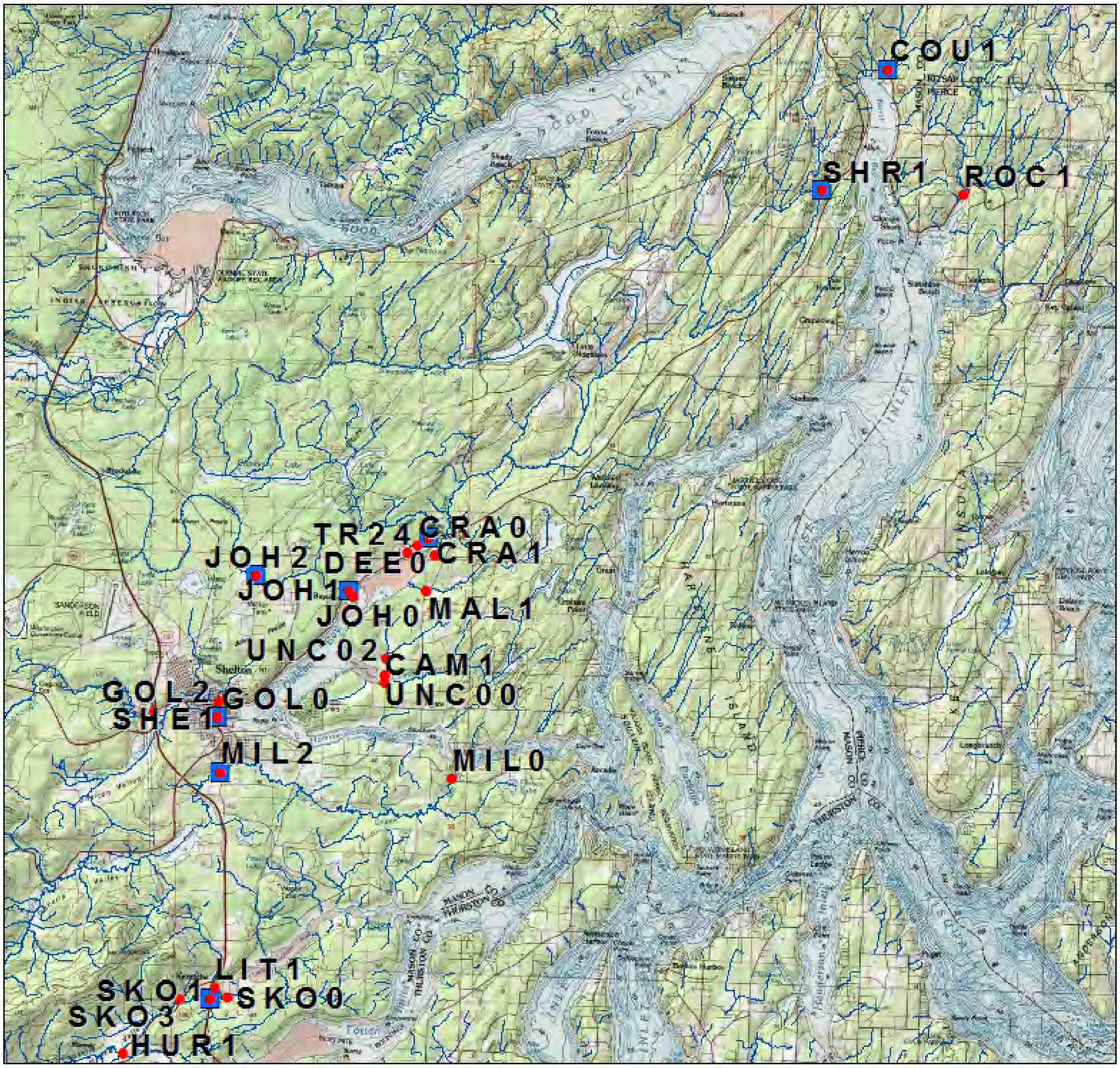
Squaxin Island Tribe Water Quality and Quantity Sampling Stations

Legend

- Squaxin WQ Stations
- Squaxin Gaging Stations

0 2.25 4.5 9 Miles

N



Squaxin Island Tribe Water Quality and Quantity sampling stations

Legend

- Squaxin WQ Stations
- Squaxin Gaging Stations

0 1.25 2.5 5 Miles

N

Squaxin Island Tribe Water Quality and Quantity sampling stations

Legend

- Squaxin WQ Stations
- Squaxin Gaging Stations

0 0.275 0.55 1.1 Miles

N

Squaxin Island Tribe Water Quality and Quantity sampling stations

Legend

- Squaxin WQ Stations
- Squaxin Gaging Stations

0 0.375 0.75 1.5 Miles

N

Squaxin Island Tribe Water Quality and Quantity sampling stations

Legend

- Squaxin WQ Stations
- Squaxin Gaging Stations

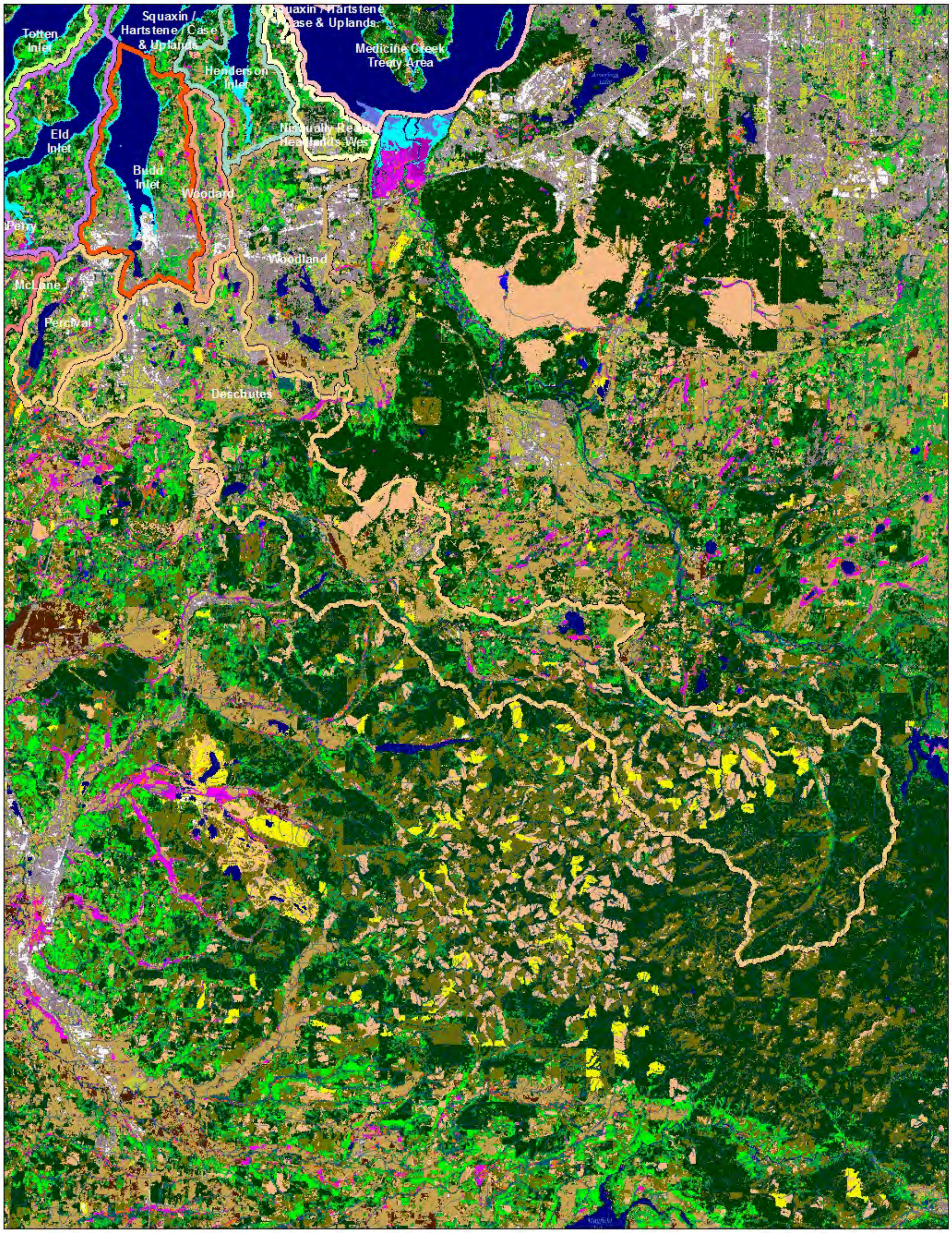
0 0.15 0.3 0.6 Miles

N

Squaxin Island Tribe
Basin Land Cover

0 2 4 8 Miles

N



Squaxin Island Tribe
Basin Land Cover- Deschutes Basin

0 2.5 5 10 Miles

N

Regional Land Cover Classification Scheme

The following information provides a description of land cover classes used with NOAA's Coastal Change Analysis Program (C-CAP) Regional land cover products. These classes have been targeted as important indicators of coastal ecosystems and have been identified as features that can be consistently and accurately derived primarily through remote-sensing means.

These descriptions have been revised from those originally published in *NOAA Coastal Change Analysis Program (C-CAP): Guidance for Regional Implementation*.

Unclassified

Background (0) – areas within the image file limits but containing no data values.

Unclassified (1) – areas in which land cover cannot be determined; these include clouds and deep shadow.

Developed Land

Developed, High Intensity (2) – contains significant land area and is covered by concrete, asphalt, and other constructed materials. Vegetation, if present, occupies less than 20 percent of the landscape. Constructed materials account for 80 to 100 percent of the total cover. This class includes heavily built-up urban centers and large constructed surfaces in suburban and rural areas with a variety of land uses.

Developed, Medium Intensity (3) – contains areas with a mixture of constructed materials and vegetation or other cover. Constructed materials account for 50 to 79 percent of total area. This class commonly includes multi- and single-family housing areas, especially in suburban neighborhoods, but may include all types of land use.

Developed, Low Intensity (4) – contains areas with a mixture of constructed materials and substantial amounts of vegetation or other cover. Constructed materials account for 21 to 49 percent of total area. This subclass commonly includes single-family housing areas, especially in rural neighborhoods, but may include all types of land use.

Developed, Open Space (5) – contains areas with a mixture of some constructed materials, but mostly managed grasses or low-lying vegetation planted in developed areas for recreation, erosion control, or aesthetic purposes. These areas are maintained by human activity such as fertilization and irrigation, are distinguished by enhanced biomass productivity, and can be recognized through vegetative indices based on spectral characteristics. Constructed surfaces account for less than 20 percent of total land cover.

Agricultural Land

Cultivated Crops (6) – contains areas intensely managed for the production of annual crops. Crop vegetation accounts for greater than 20 percent of total vegetation. This class also includes all land being actively tilled.

Pasture/Hay (7) – contains areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops, typically on a perennial cycle and not tilled. Pasture/hay vegetation accounts for greater than 20 percent of total vegetation.

Grassland

Grassland/Herbaceous (8) – contains areas dominated by grammanoid or herbaceous vegetation, generally greater than 80 percent of total vegetation. These areas are not subject to intensive management such as tilling but can be utilized for grazing.

Forest Land

Deciduous Forest (9) – contains areas dominated by trees generally greater than 5 meters tall and greater than 20 percent of total vegetation cover. More than 75 percent of the tree species shed foliage simultaneously in response to seasonal change.

Evergreen Forest (10) – contains areas dominated by trees generally greater than 5 meters tall and greater than 20 percent of total vegetation cover. More than 75 percent of the tree species maintain their leaves all year. Canopy is never without green foliage.

Mixed Forest (11) – contains areas dominated by trees generally greater than 5 meters tall, and greater than 20 percent of total vegetation cover. Neither deciduous nor evergreen species are greater than 75 percent of total tree cover. *Both coniferous and broad-leaved evergreens are included in this category.*

Scrub Land

Scrub/Shrub (12) – contains areas dominated by shrubs less than 5 meters tall with shrub canopy typically greater than 20 percent of total vegetation. This class includes tree shrubs, young trees in an early successional stage, or trees stunted from environmental conditions.

Barren Land

Barren Land (20) – contains areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits, and other accumulations of earth material. Generally, vegetation accounts for less than 10 percent of total cover.

Tundra (24) – is categorized as a treeless region beyond the latitudinal limit of the boreal forest in pole-ward regions and above the elevation range of the boreal forest in high mountains. In the United States, tundra occurs primarily in Alaska.

Perennial Ice/Snow (25) – includes areas characterized by a perennial cover of ice and/or snow, generally greater than 25 percent of total cover.

Palustrine Wetlands

Palustrine Forested Wetland (13) – includes tidal and nontidal wetlands dominated by woody vegetation greater than or equal to 5 meters in height, and all such wetlands that occur in tidal areas in which salinity due to ocean-derived salts is below 0.5 percent. Total vegetation coverage is greater than 20 percent.

Palustrine Scrub/Shrub Wetland (14) – includes tidal and nontidal wetlands dominated by woody vegetation less than 5 meters in height, and all such wetlands that occur in tidal areas in which salinity due to ocean-derived salts is below 0.5 percent. Total vegetation coverage is greater than 20 percent. *Species present could be true shrubs, young trees and shrubs, or trees that are small or stunted due to environmental conditions.*

Palustrine Emergent Wetland (Persistent) (15) – includes tidal and nontidal wetlands dominated by persistent emergent vascular plants, emergent mosses or lichens, and all such wetlands that occur in tidal areas in which salinity due to ocean-derived salts is below 0.5 percent. Total vegetation cover is greater than 80 percent. *Plants generally remain standing until the next growing season.*

Estuarine Wetlands

Estuarine Forested Wetland (16) – includes tidal wetlands dominated by woody vegetation greater than or equal to 5 meters in height, and all such wetlands that occur in tidal areas in which salinity due to ocean-derived salts is equal to or greater than 0.5 percent. Total vegetation coverage is greater than 20 percent.

Estuarine Scrub/Shrub Wetland (17) – includes tidal wetlands dominated by woody vegetation less than 5 meters in height, and all such wetlands that occur in tidal areas in which salinity due to ocean-derived salts is equal to or greater than 0.5 percent. Total vegetation coverage is greater than 20 percent.

Estuarine Emergent Wetland (18) – Includes all tidal wetlands dominated by erect, rooted, herbaceous hydrophytes (excluding mosses and lichens). These wetlands occur in tidal areas in which salinity due to ocean-derived salts is equal to or greater than 0.5 percent and are present for most of the growing season in most years. Total vegetation cover is greater than 80 percent. *Perennial plants usually dominate these wetlands.*

Barren Land

Unconsolidated Shore (19) – includes material such as silt, sand, or gravel that is subject to inundation and redistribution due to the action of water. Substrates lack vegetation except for pioneering plants that become established during brief periods when growing conditions are favorable.

Water and Submerged Lands

Open Water (21) – includes areas of open water, generally with less than 25 percent cover of vegetation or soil.

Palustrine Aquatic Bed (22) – includes tidal and nontidal wetlands and deepwater habitats in which salinity due to ocean-derived salts is below 0.5 percent and which are dominated by plants that grow and form a continuous cover principally on or at the surface of the water. These include algal mats, detached floating mats, and rooted vascular plant assemblages. Total vegetation cover is greater than 80 percent.

Appendix 2. Summary data for all long term sampling sites.

	Start Date	End Date	# of Samples	Min Value	Max Value	Arithmatic Mean	Geometric Mean	Comments
CAM1								
Ammonia (mg/l)	10/12/09	9/10/14	5	0.011	0.037	0.03		
Fecal Coliform (#/100ml)	**1/4/05**	**12/4/14**	**103**	**1**	**880**	**54**	**23**	
Inorganic nitrogen (nitrate and nitrite) (mg/l)	10/18/10	9/10/14	5	0.064	0.069	0.07		
Nutrient-nitrogen (mg/l)	12/13/06	9/10/14	7	0.06	0.363	0.16		
pH	12/2/03	4/12/10	40	6.39	8.84	8.0		
Phosphorus (mg/l)	12/13/06	9/10/14	9	0.0223	0.0873	0.05		
Salinity (PSS)	12/2/03	4/12/10	30	0	96.4	13.05		
Specific conductance (mS/cm)	12/2/03	4/12/10	40	0.196	44.5	14.05		
Total suspended solids (mg/l)	10/15/12	12/4/14	27	3	61	15.1	11	
Turbidity (ntu)	6/14/05	8/10/09	31	6	5999	247	40	
COU1								Picked up this site in 2013 for monthly fecal coliform and annual nitrogen, phosphorus.
Ammonia (mg/l)	9/5/13	9/10/14	2	0	0			
Fecal Coliform (#/100ml)	**10/15/12**	**12/4/14**	**27**	**1**	**280**	**32**	**15**	
Inorganic nitrogen (nitrate and nitrite)	9/5/13	9/10/14	2	0.065	0.067			
Nutrient-nitrogen	9/5/13	9/10/14	2	0.065	0.067			
pH	12/9/03	12/9/03	1	7.03	7.03			
Phosphorus	9/5/13	9/10/14	2	0.0392	0.0418			
Specific conductance	12/9/03	12/9/03	1	0.041	0.041			
Turbidity	12/9/03	12/9/03	1	0	0			
CRA0								Moved Cranberry sample site from CRA1 to CRA0, inside the Twin River Ranch in summer 2006.
Ammonia (mg/l)	9/17/12	11/25/14	4	0.025	0.207	0.12		
Fecal Coliform (#/100ml)	**8/9/06**	**12/4/14**	**46**	**1**	**940**	**56**	**22**	
Inorganic nitrogen (nitrate and nitrite)	9/17/12	11/25/14	5	0.061	0.396	0.17		
Nutrient-nitrogen	9/17/12	9/10/14	3	0.061	0.156	0.10		
pH	6/27/06	9/8/08	8	6.4	8.45	7.8		
Phosphorus	9/17/12	9/10/14	3	0.0242	0.505	0.18		
Salinity	6/27/06	9/8/08	8	0.03	0.04	0.03		
Specific conductance	6/27/06	9/8/08	8	0.057	0.071	0.07		
Total suspended solids	**10/15/12**	**12/4/14**	**27**	**1**	**14**	**4.8**	**4**	
Turbidity	6/27/06	9/8/08	8	0.6	86.2	25	10	
CRA1								Collected data here and at CRA0 until 2012, when we switched to primarily CRA0.
Ammonia (mg/l)	10/12/09	9/17/12	3	0.048	0.048	0.05		
Fecal Coliform (#/100ml)	**12/7/04**	**7/15/14**	**79**	**1**	**590**	**47**	**20**	
Inorganic nitrogen (nitrate and nitrite)	10/18/10	9/17/12	3	0.115	0.192	0.15		
Nutrient-nitrogen	12/13/06	9/17/12	6	0.115	102	17.17		
pH	11/18/03	4/12/10	46	0.06	9.3	7.6		
Phosphorus	12/13/06	9/17/12	7	0.0251	95	13.61		
Salinity	12/2/03	4/12/10	33	0.01	96.9	2.96		
Specific conductance	11/18/03	4/12/10	48	0.028	37.6	0.84		
Turbidity	11/18/03	8/10/09	36	0.2	328	32	11	

	Start Date	End Date	# of Samples	Min Value	Max Value	Arithmatic Mean	Geometric Mean	Comments
DEE0								
Ammonia (mg/l)	10/12/09	11/25/14	6	0.012	0.058	0.02		
Fecal Coliform (#/100ml)	**12/7/04**	**12/4/14**	**110**	**2**	**730**	**51**	**23**	
Inorganic nitrogen (nitrate and nitrite)	10/18/10	11/25/14	7	0.078	0.441	0.15		
Nutrient-nitrogen	11/5/08	9/10/14	5	0.093	0.9	0.28		
pH	12/7/04	4/12/10	40	0.07	9.29	7.7		
Phosphorus	11/5/08	9/10/14	7	0.0333	0.0484	0.04		
Salinity	6/14/05	4/12/10	31	0.02	21.1	0.83		
Specific conductance	12/7/04	4/12/10	41	0.03	5.15	0.27		
Total suspended solids	**10/15/12**	**12/4/14**	**27**	**2**	**10**	**3.9**	**4**	
Turbidity	6/14/05	8/10/09	32	0	169	26		
GOL0								
Ammonia (mg/l)	10/12/09	11/25/14	6	0.012	0.012	0.01		
Fecal Coliform (#/100ml)	**12/7/04**	**12/4/14**	**100**	**2**	**750**	**54**	**28**	
Inorganic nitrogen (nitrate and nitrite)	10/18/10	11/25/14	7	0.089	0.278	0.13		
Nutrient-nitrogen	12/13/06	9/10/14	6	0.073	0.193	0.11		
pH	11/9/04	4/12/10	26	6.67	8.94	7.8		
Phosphorus	12/13/06	9/10/14	7	0.0187	0.0287	0.02		
Salinity	6/14/05	4/12/10	15	0.03	0.07	0.05		
Specific conductance	11/9/04	4/12/10	26	0.058	0.147	0.10		
Total suspended solids	**11/27/12**	**12/4/14**	**26**	**1**	**13**	**3.3**	**3**	
Turbidity	6/14/05	9/16/08	18	3.3	392	42	15	
HUR1								
Ammonia (mg/l)	10/12/09	9/10/14	5	0.014	0.048	0.03		
Fecal Coliform (#/100ml)	**10/25/06**	**12/4/14**	**81**	**1**	**2800**	**115**	**36**	
Inorganic nitrogen (nitrate and nitrite)	10/18/10	9/10/14	5	0.06	0.126	0.09		
Nutrient-nitrogen	12/20/06	9/10/14	7	0.093	97	14.08		
pH	12/4/03	4/12/10	17	6.8	9.19	8.0		
Phosphorus	12/20/06	9/10/14	7	0.0111	0.0492	0.03		
Salinity	10/25/06	4/12/10	16	0.01	0.06	0.05		
Specific conductance	12/4/03	4/12/10	17	0	0.134	0.09		
Total suspended solids	**2/19/13**	**12/4/14**	**23**	**1**	**9**	**3.4**	**3**	
Turbidity	12/4/03	8/10/09	16	1.8	44.3	23	19	
JOH0								
Ammonia (mg/l)	1/23/13	11/25/14	24	0.013	0.522	0.13		Monthly measurments of Nitrogen, total suspended solids were started at this site in January 2013, one year prior to the closure of the Bayshore Golf Course.
Fecal Coliform (#/100ml)	**12/7/04**	**12/4/14**	**40**	**2**	**240**	**27**	**15**	
Inorganic nitrogen (nitrate and nitrite)	**1/23/13**	**11/25/14**	**31**	**0.196**	**0.589**	**0.32**		
Nutrient-nitrogen	**1/23/13**	**10/21/14**	**22**	**0.196**	**1.054**	**0.36**		
pH	12/7/04	11/7/05	12	7.04	8.05	7.7		
Phosphorus	9/5/13	9/10/14	2	0.0187	0.0235	0.02		
Salinity	6/14/05	8/2/05	2	0.03	0.04	0.04		
Specific conductance	12/7/04	11/7/05	12	0.052	0.076	0.06		
Total suspended solids	**10/15/12**	**12/4/14**	**27**	**1**	**13**	**3.9**	**3**	
Turbidity	6/14/05	11/7/05	6	1.9	93.9	24	12	

	Start Date	End Date	# of Samples	Min Value	Max Value	Arithmatic Mean	Geometric Mean	Comments
JOH1								This was originally, the site for monthly fecal coliform measurments, but we switched to sampling downstream at JOH0 in January 2013, one year prior to the closure of the Bayshore Golf Course.
Ammonia (mg/l)	10/12/09	9/17/12	3	0.025	0.134	0.08		
Fecal Coliform (#/100ml)	**12/7/04**	**9/17/12**	**79**	**1**	**180**	**25**	**14**	
Inorganic nitrogen (nitrate and nitrite)	10/18/10	9/17/12	3	0.21	0.366	0.31		
Nutrient-nitrogen	12/13/06	9/17/12	5	0.21	0.425	0.32		
pH	11/18/03	4/12/10	42	6.32	9.12	8.0		
Phosphorus	12/13/06	9/17/12	6	0.0198	0.078	0.04		
Salinity	12/2/03	4/12/10	30	0	99	3.33		
Specific conductance	11/18/03	4/12/10	42	0.001	0.09	0.07		
Turbidity	11/18/03	8/10/09	33	1	148	22	11	
LIT1								
Ammonia (mg/l)	10/12/09	9/10/14	5	0.037	0.037	0.04		
Fecal Coliform (#/100ml)	**10/25/06**	**12/4/14**	**84**	**1**	**2100**	**94**	**29**	
Inorganic nitrogen (nitrate and nitrite)	10/18/10	9/10/14	5	0.701	1.11	0.89		
Nutrient-nitrogen	12/20/06	9/10/14	7	0.701	1.16	0.92		
pH	12/4/03	4/12/10	20	7.39	8.92	8.1		
Phosphorus	12/20/06	9/10/14	8	0.013	0.0464	0.03		
Salinity	10/25/06	4/12/10	19	0.02	0.08	0.05		
Specific conductance	12/4/03	4/12/10	20	0.039	0.177	0.11		
Total suspended solids	**3/21/13**	**12/4/14**	**22**	**1**	**31**	**5.7**	**3**	
Turbidity	12/4/03	4/6/09	19	2.4	582	55	13	
MAL1								
Ammonia (mg/l)	10/12/09	9/10/14	5	0	0			
Fecal Coliform (#/100ml)	**12/7/04**	**12/4/14**	**104**	**2**	**800**	**76**	**27**	
Inorganic nitrogen (nitrate and nitrite)	10/18/10	9/10/14	5	0.036	0.049	0.04		
Nutrient-nitrogen	12/13/06	9/10/14	7	0.012	0.193	0.08		
pH	12/2/03	4/12/10	40	6.61	9.18	8.0		
Phosphorus	12/13/06	9/10/14	9	0.012	94	10.46		
Salinity	12/2/03	4/12/10	29	0.01	95	3.31		
Specific conductance	12/2/03	4/12/10	40	0.028	0.099	0.07		
Total suspended solids	**10/15/12**	**12/4/14**	**27**	**1**	**8**	**2.7**	**2**	
Turbidity	6/14/05	8/10/09	31	2	92	24	13	
MIL0								
Ammonia (mg/l)	10/12/09	11/25/14	6	0.01	0.086	0.03		
Fecal Coliform (#/100ml)	**12/7/04**	**12/4/14**	**101**	**1**	**590**	**38**	**18**	
Inorganic nitrogen (nitrate and nitrite)	10/18/10	11/25/14	7	0.046	0.574	0.13		
Nutrient-nitrogen	12/13/06	9/10/14	8	0.06	0.38	0.16		
pH	12/7/04	4/12/10	24	7.53	9.66	8.2		
Phosphorus	12/13/06	9/10/14	9	0.025	0.0503	0.03		
Salinity	6/14/05	4/12/10	21	0	21.61	1.53		
Specific conductance	12/7/04	4/12/10	28	0.043	35.2	2.00		
Total suspended solids	**11/27/12**	**12/4/14**	**26**	**2**	**15**	**6.0**	**5**	
Turbidity	6/14/05	3/9/09	21	1.2	148	30	16	

	Start Date	End Date	# of Samples	Min Value	Max Value	Arithmatic Mean	Geometric Mean	Comments
ROC1								Decided in 2012 to put this site in the long-term group.
Ammonia (mg/l)	9/5/13	9/10/14	2	0.088	0.088	0.09		
Fecal Coliform (#/100ml)	**10/15/12**	**12/4/14**	**27**	**1**	**490**	**59**	**20**	
Inorganic nitrogen (nitrate and nitrite)	9/5/13	9/10/14	2	0.315	0.391			
Nutrient-nitrogen	9/5/13	9/10/14	2	0.391	0.403			
pH	12/9/03	12/9/03	1	6.92	6.92			
Phosphorus	9/5/13	9/10/14	2	0.0209	0.0229			
Specific conductance	12/9/03	12/9/03	1	0.034	0.034			
Turbidity	12/9/03	12/9/03	1	0	0			
SHE1								
Ammonia (mg/l)	10/12/09	11/25/14	6	0.016	0.085	0.05		
Fecal Coliform (#/100ml)	**12/7/04**	**12/4/14**	**109**	**1**	**2300**	**170**	**69**	
Inorganic nitrogen (nitrate and nitrite)	10/18/10	11/25/14	7	0.27	0.54	0.34		
Nutrient-nitrogen	12/13/06	9/10/14	7	0.246	0.488	0.32		
pH	12/9/03	4/12/10	35	6.86	9.05	8.0		
Phosphorus	12/13/06	9/10/14	8	0.0309	0.0589	0.05		
Salinity	6/14/05	4/12/10	23	0.02	0.07	0.05		
Specific conductance	12/9/03	4/12/10	35	0.033	0.149	0.11		
Total suspended solids	**11/27/12**	**12/4/14**	**25**	**2**	**11**	**4.3**	**4**	
Turbidity	12/9/03	4/6/09	27	2.8	381	35	16	
SHR1								Decided in 2012 to put this site in the long-term group.
Ammonia (mg/l)	9/5/13	9/10/14	2	0.011	0.011	0.01		
Fecal Coliform (#/100ml)	**10/15/12**	**12/4/14**	**36**	**4**	**860**	**50**	**20**	
Inorganic nitrogen (nitrate and nitrite)	9/5/13	9/10/14	2	0.041	0.059			
Nutrient-nitrogen	9/5/13	9/10/14	2	0.041	0.07			
pH	12/9/03	12/9/03	1	7.11	7.11			
Phosphorus	9/5/13	9/10/14	2	0.0404	0.0497			
Specific conductance	12/9/03	12/9/03	1	0.041	0.041			
Turbidity	12/9/03	12/9/03	1	5.5	5.5		6	
SKO0								
Ammonia (mg/l)	10/12/09	9/10/14	5	0.023	0.073	0.05		
Fecal Coliform (#/100ml)	**10/25/06**	**12/4/14**	**89**	**4**	**1400**	**127**	**43**	
Inorganic nitrogen (nitrate and nitrite)	10/18/10	9/10/14	5	0.19	0.48	0.31		
Nutrient-nitrogen	12/20/06	9/10/14	7	0.205	0.795	0.42		
pH	10/25/06	4/12/10	17	7.21	9.2	8.1		
Phosphorus	12/20/06	9/10/14	9	0.0187	96	10.70		
Salinity	10/25/06	4/12/10	17	0.03	2.34	0.39		
Specific conductance	10/25/06	4/12/10	17	0.068	4.43	0.76		
Total suspended solids	**2/19/13**	**12/4/14**	**22**	**2**	**19**	**6.0**	**5**	
Turbidity	10/25/06	8/10/09	16	6.6	72	21	16	

	Start Date	End Date	# of Samples	Min Value	Max Value	Arithmatic Mean	Geometric Mean	Comments
SKO3								
Ammonia (mg/l)	10/12/09	9/10/14	6	0.01	0.024	0.01		
Fecal Coliform (#/100ml)	**10/25/06**	**12/4/14**	**88**	**4**	**1600**	**115**	**44**	
Inorganic nitrogen (nitrate and nitrite)	10/18/10	9/10/14	5	0.113	0.454	0.23		
Nutrient-nitrogen	12/20/06	9/10/14	7	0.125	0.82	0.35		
pH	11/18/03	4/12/10	25	5.95	8.97	8.0		
Phosphorus	12/20/06	9/10/14	8	0.0127	0.04	0.02		
Salinity	10/25/06	4/12/10	23	0	0.06	0.04		
Specific conductance	11/18/03	4/12/10	25	0.001	0.115	0.08		
Total suspended solids	**2/19/13**	**12/4/14**	**23**	**1**	**20**	**5.2**	**4**	
Turbidity	11/18/03	8/10/09	24	6	757	56	19	
TR24								
Ammonia (mg/l)	9/17/12	9/10/14	3	0	0			
Fecal Coliform (#/100ml)	**8/6/06**	**12/4/14**	**88**	**1**	**2200**	**260**	**59**	
Inorganic nitrogen (nitrate and nitrite)	9/17/12	9/10/14	3	0.023	0.032	0.03		
Nutrient-nitrogen	12/13/06	9/10/14	6	0.012	0.225	0.06		
pH	8/22/06	4/6/09	22	6.49	9	8.0		
Phosphorus	12/13/06	9/10/14	6	0.0153	0.0757	0.06		
Salinity	8/22/06	4/6/09	22	0.01	14.14	0.95		
Specific conductance	8/22/06	4/6/09	22	0.029	23.7	1.65		
Total suspended solids	**11/27/12**	**12/4/14**	**26**	**2**	**54**	**8.2**	**6**	
Turbidity	8/22/06	4/6/09	22	10.3	1169	201	71	
UNC02								
Ammonia (mg/l)	9/5/13	9/10/14	2	0.016	0.053	0.03		
Fecal Coliform (#/100ml)	**12/7/04**	**12/4/14**	**71**	**1**	**440**	**74**	**34**	
Inorganic nitrogen (nitrate and nitrite)	9/5/13	9/10/14	2	0.049	0.076	0.06		
Nutrient-nitrogen	12/13/06	9/10/14	4	0.071	0.521	0.20		
pH	12/2/03	4/9/08	28	5.59	8.79	7.5		
Phosphorus	12/13/06	9/10/14	4	0.0129	0.032	0.02		
Salinity	12/2/03	4/9/08	17	0.01	95.8	5.67		
Specific conductance	12/2/03	4/9/08	28	0	0.124	0.06		
Total suspended solids	**11/27/12**	**12/4/14**	**26**	**1**	**6**	**2.8**	**3**	
Turbidity	6/14/05	4/9/08	20	5.3	355	43	21	
UNC00								
Ammonia (mg/l)	10/12/09	9/10/14	4	0.015	0.046	0.04		
Fecal Coliform (#/100ml)	**12/7/04**	**12/4/14**	**98**	**2**	**2500**	**114**	**34**	
Inorganic nitrogen (nitrate and nitrite)	9/17/12	9/10/14	3	0.18	0.314	0.26		
Nutrient-nitrogen	12/13/06	9/10/14	6	0.085	0.483	0.28		
pH	12/2/03	4/12/10	45	5.67	8.89	7.7		
Phosphorus	12/13/06	9/10/14	7	0.0221	0.0635	0.04		
Salinity	12/2/03	4/12/10	35	0	96.5	11.26		
Specific conductance	12/2/03	4/12/10	45	0	44.2	12.23		
Total suspended solids	**10/15/12**	**12/4/14**	**26**	**2**	**55**	**8.4**	**6**	
Turbidity	6/14/05	8/10/09	36	1.9	820	84	40	

APPENDIX B

SUNA V.2 Nitrate Probe Standard Operating Procedure

SQUAXIN ISLAND TRIBE
LONG-TERM STREAM MONITORING PROGRAM

STANDARD OPERATING PROCEDURES FOR CONTINUOUS NITRATE MONITORING IN STREAMS
VERSION 1.0

Prepared for
Squaxin Island Tribe

Prepared by
Herrera Environmental Consultants, Inc.

Note:
Some pages in this document have been purposely skipped or blank pages inserted so that this document will copy correctly when duplexed.

SQUAXIN ISLAND TRIBE
LONG-TERM STREAM MONITORING PROGRAM

STANDARD OPERATING PROCEDURES FOR CONTINUOUS NITRATE MONITORING IN STREAMS
VERSION 1.0

Prepared for
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October 15, 2015

1. PURPOSE AND SCOPE

This Standard Operating Procedure (SOP) details methods used by the Squaxin Island Tribe (SIT) to collect continuous nitrate monitoring data. SIT purchased a SUNA V2 nitrate meter in August, 2013 and is planning to begin using it in October 2015. The scope of the continuous nitrate monitoring program currently focuses on year-round deployment at one sampling site. It also applies to other deployment methods such as short-term deployment at multiple sites throughout the year.

The intended purpose of the continuous nitrate monitoring program is to collect diel stream nitrate data that may be used to expand the interpretation of a site's nitrate sampling and analysis results, and to identify periods of elevated nitrate concentrations for source evaluation and control.

2. APPLICABILITY

The SOP will be followed for the installation and maintenance of a continuous nitrate monitoring station in ***freshwater locations only***. The specific station and deployment method has yet to be determined. These protocols reflect in part those specified in the User's Manual (Satlantic 2014), those recommended by the US Geological Society (Pellarin et al. 2013), and those used in the Deschutes River by the Washington State Department of Ecology (Ecology 2014).

3. DEFINITIONS

DOM	Dissolved Organic Matter
IBW	Inorganic-grade blank water
uM	Micro Molar
PDT	Pacific Daylight Time
PST	Pacific Standard Time
SIT	Squaxin Island Tribe
SOP	Standard Operating Procedure
VDC	Volts Direct Current
USGS	United States Geological Survey
UV	Ultra Violet

4. PERSONNEL QUALIFICATIONS/RESPONSIBILITIES

Qualified personnel will have 2 years of experience with flow and water quality monitoring, including meter operation for instantaneous and continuous measurements, and recent familiarity with the monitoring site and SUNA SOP and Manual. Data managers will have experience with Aquarius Software and time-series statistical analysis.

5. EQUIPMENT, REAGENTS, AND SUPPLIES

5.1 *Specialized Field Equipment*

5.1.1 SUNA in-situ deployment cage

5.2 SUNA mounting hardware

5.3 SUNA V2 nitrate probe

5.4 Copper anti-fouling guard

5.5 Reagent grade nitrate-free water for baseline calibration check

5.6 Computer with most recent SUNACom software

5.7 Serial connection cable for connecting SUNA nitrate probe to computer

5.8 Nylon brushes for cleaning the sensor window

5.9 Lint free lens wipes for sensor window cleaning

5.10 *Laboratory Supplies*

5.10.1 Nitrate-free water (e.g., IBW)

5.10.2 Standard solutions of known nitrate concentration

6. SUMMARY OF PROCEDURE

6.1 *Pre-Deployment Run Preparation*

6.1.1 <u>Visual Inspection</u>

6.1.1.1 Ensure that all manufacturer documentation, calibration reports, and serial numbers are recorded and maintained.

6.1.1.2 Visually inspect the instrument body for defects, blemishes, or imperfections and record all evidence of scratches, dents, nicks, or cracks, and photograph observed changes in the instrument body.

6.1.1.3 With the instrument off, visually examine the optical windows for scratching, pitting, staining, or misalignment with the sensor body

6.1.1.4 Inspect the electrical connector and associated cables for kinks, nicks, corrosion, or bent pins and contacts.

6.1.1.5 Visually examine all ancillary components, such as wipers and controllers, for evidence of damage or corrosion.

6.1.1.6 Record all inspection results (written and photographs) and contact the manufacturer immediately with concerns.

6.1.2 Software Setup

6.1.2.1 Ensure that the most recent version of the SUNACom software is installed. (See SUNA user manual for installation procedure) (Satlantic 2014).

6.1.2.2 Select **Start->Programs->SUNACom** to run SUNACOM

6.1.2.3 Connect SUNA to 12 VDC power source such as a deep cycle marine battery or appropriately specified AC adapter.

6.1.2.4 Connect the SUNA serial connection cable, or USB to an available serial or USB port on your computer.

6.1.2.5 Press **Connect** to cause SUNACom to enter Setup mode; once connected all buttons on the dashboard will enable (i.e., can be clicked).

6.1.2.6 Select **SUNA Settings** button to open the settings dialog.

6.1.2.7 If the Settings fails to open or reports an error, then there is a problem with the serial connection. (See Troubleshooting section in user manual for assistance) (Satlantic 2014).

6.1.2.8 Select and review settings. Press F1 key for help on any selected setting.

6.1.2.9 Press **Cancel** to continue with default settings or **OK** to apply changes.

6.1.3 Data Acquisition Test

6.1.3.1 Connect the SUNA via Serial or USB interface.

6.1.3.2 Run the SUNA Self Test by navigating From the *Advanced* submenu in the *Sensor* menu.

6.1.3.3 Place the SUNA in a clean, nitrate-free water sample (e.g., inorganic grade blank water or distilled deionized water).

6.1.3.4 Press the **Start** button *Note: it is important to match the time duration (e.g., 2-minute average) of data acquisition during test procedures to that which will be used in the field to account for "warm up drift."*

6.1.3.5 If the nitrate reading is <-2 or >2 uM, then the instrument has drifted, and the calibration should be updated.

6.1.3.6 To update the calibration and correct the drift, stop the current Acquisition and press **Update Calibration.**

6.1.3.7 Perform another Acquisition with clean, nitrate-free water to make sure the calibration update was successful.

6.1.4 Accuracy and Precision Testing

6.1.4.1 Prepare or purchase a series of five (5) reagent-grade standard nitrate solutions for the range of concentrations expected at the deployment site. Verify that the accuracy is within acceptable limits and that the instrument response is linear across the range of nitrate concentrations. Procedures for validating precision, accuracy and linearity are described in USGS (2013).

6.1.4.2 Repeat the accuracy, precision, and linearity checks with standard solutions spiked in natural waters (that is, matrix spikes) collected from the deployment site or a similar environment. Water samples for matrix spikes should be collected during both base flow and storm flow conditions to evaluate potential interference from turbidity and dissolved organic matter (DOM). Recovery of the nitrate spike is to be within accuracy specifications of the sensor in the absence of significant matrix interferences. If the matrix spike recovery is not within three times those specifications, further evaluation of the nature of the interferences (such as a dilution series) is warranted. The accuracy specification is to be within 2 µM (0.028 mg/L) or 10 percent, whichever is higher for freshwater solutions with less than 1,000 µM (14 mg/L) of nitrate and the standard 10 mm path length (Satlantic 2015). Thus, the matrix spike recovery should be within 70 to 130 percent at nitrate concentrations exceeding 20 µM (0.28 mg/L). Further information on testing instrument performance by using matrix spikes is provided in USGS (2013).

6.1.4.3 If elevated turbidity or DOM is expected at the deployment site, but not present in the available matrix water, the performance of the instrument in the presence of these interferences can be verified by using standard reference materials. Although a variety of standard references are available, materials that are reflective of natural waters, such as Elliot Silt Loam soil or

Suwanee River natural organic matter (available from the International Humic Substances Society, www.humicsubstances.org), are preferred to synthetic reference materials, such as formazin or polymer beads.

6.1.5 Documentation Procedures

6.1.5.1 Record all the field data including, location, site description, deployment mounting configuration, and problems encountered. It is advised to develop and use a specific form or checklist so that consistent deployment data may be collected from all sites, should future continuous nitrate monitoring stations be established.

6.1.5.2 Record all observation times in PST (or note when they are PDT, so they may be converted to PST later).

6.1.5.3 Draw a map and describe the general area noting the logger location, land mark references. *Note: if possible, draw the map with north being toward the top of the page or denote the direction of north on the drawing.*

6.1.5.4 Take upstream and downstream photographs of the nitrate probe location that include some visual marker to use along with the information on the survey form to help relocate and retrieve the device in the future.

6.1.6 Programming the SUNA for Field Operation

6.1.6.1 Connect the serial connection or USB cable from a computer running SUNACom to the SUNA. Press the **Connect** button, and enter the Setup mode.

6.1.6.2 Open the SUNA Settings Menu and Select **Periodic** in the "Operation Mode" drop down menu.

6.1.6.3 Select the desired sample interval (e.g., 15 minutes), and set a desired sample timing offset if sampling is to occur at times other than 00:00, 00:15, 00:30, and so on and so forth.

6.1.6.4 Input a desired sample duration (time, or number of frames).

6.1.6.5 Enable the wiper by clicking the check box.

6.1.6.6 As the SUNA collects samples, it generates a log of instrument information that can later be used for identifying instrument malfunctions. The level of detail of information logged can be set by the user. Set the logging level to select the desired message sensitivity. It is recommended to select "INFO," which is the typical log level for interactive use and development.

6.1.6.7 Disconnect from SUNACom, and disconnect the serial connection or USB cable from the SUNA.

6.2 *Instrument Deployment*

6.2.1 Physical Infrastructure

6.2.1.1 An in-situ configuration will be used at the nitrate sampling site. In this configuration, the sensor is placed at the sampling site, and should be protected from debris and vandalism by some form of housing (e.g., slotted PVC or stainless steel pipe). Install the pipe housing in a horizontal position near the deepest part of the stream channel at an elevation just below the low water level. Secure the housing to the stream bed with rebar and hose clamps or some other means. Adjust the housing position as necessary to avoid debris or sediment accumulation.

6.2.2 Sensor Mounting

6.2.2.1 Mount the SUNA in a horizontal orientation with the gap in the optical chamber open vertically (i.e., opening up for air to escape and opening down for sediment to sink) to reduce the possibility of sediment collection on the optical windows. Anything that interferes with the light path may adversely affect the data.

6.2.3 Anti-Fouling

6.2.3.1 Install the copper bio-fouling guard according to manufacturer instructions. (SUNA Manual p. 65) (Satlantic 2013).

6.2.4 Mounting

6.2.4.1 Turn the SUNA on. Complete all calibration procedures, and ensure that acquisition settings are correct. Mount the instrument in the site-specific mounting apparatus.

6.2.5 Field Servicing (every 4-6 weeks at minimum)

6.2.5.1 Perform a site inspection documenting site conditions and state of the infrastructure. Document changes in biological, physical and hydrologic conditions (e.g., water level relative to the sensor).

6.2.5.2 Collect a grab sample, concurrent in time and adjacent to the sensor for laboratory analysis to check for sensor accuracy.

6.2.5.3 Remove the sensor from the mounting location.

6.2.5.4 Inspect sensor condition including cables, connectors, wipers and infrastructure for; fouling, staining, and scratching of the optical windows, degraded seals, damage to the sensor housing, and damage or wear of the wiper assembly.

6.2.5.5 Clean sensor using soft nylon brushes, and lint free lens paper.

6.2.5.6 Connect the SUNA via serial connection or USB cable to a computer running SUNACom, and viewing the cumulative lamp time on the SUNACom dashboard (SUNA Lamps are rated for 900 hours).

6.2.5.7 Return the sensor to the monitoring location.

6.2.5.8 *Note: It is a good practice to check for baseline drift (Section 6.3.1) before and after removing biofouling or cleaning the sensor window to determine the effect of servicing on measured concentrations.*

6.3 *Instrument Accuracy Verification and Recalibration*

6.3.1 Determining Baseline Drift (Reality Checks), and Recalibration

6.3.1.1 Check the instrument for calibration and drift on a quarterly or more frequent basis. This is accomplished by performing the "*Reality Check*" procedure described below in the SUNACom manual (Satlantic 2015) on page 43.

6.3.1.2 *Prior to cleaning the SUNA,* immerse the SUNA in clean, nitrate-free water and acquire data.

6.3.1.3 Check the acquired data and verify that the measured nitrate concentration is between -2 and 2 uM. *Note: it is okay if the measured value is outside this range. The purpose of taking the pre-cleaning measurement is to determine if the instrument has drifted between cleanings*.

6.3.1.4 Clean the optical window using an alcohol cleaning solution and soft nylon bristle brush.

6.3.1.5 Following cleaning the optical window, immerse the SUNA in clean, nitrate-free water and acquire data.

6.3.1.6 Check the acquired data and verify that the measured nitrate concentration is between -2 and 2 uM. If the measured value is out of range, the instrument has drifted and needs to be recalibrated. *Note: if the pre, and post-cleaning values are different, the instrument needs to be cleaned more frequently.*

6.3.1.7 To update the calibration and correct the drift, stop the current Acquisition and press the **Update Calibration.**

6.3.1.8 Compare calibration file reference spectra. Each time the SUNA is calibrated it generates a calibration file that contains data required to convert a spectral measurement into a nitrate concentration. The calibration data are the wavelengths of the spectrum, the extinction coefficients of chemical species, and a reference spectrum relative to which the measurement is interpreted. It is beyond the scope of this SOP, but it can be informative to compare reference spectra among calibration files to learn about instrument performance. Reference spectra comparison is described in the SUNACom manual (Satlantic 2015) on pages 45–47.

6.3.2 Testing Against Known Standards

6.3.2.1 Every 6 weeks or more frequently, instrument performance should be verified using known standards following the procedures described in section 6.1.4.1.

6.4 *Data Management Procedures*

6.4.1 Data Download Procedures

6.4.1.1 Connect the SUNA to a computer via serial connection or USB cable and open SUNACom.

6.4.1.2 Accessing the "*View*" menu allows for viewing the time series graph, the absorbance graph, or reprocessed nitrate graphs of the data collected during the most recent deployment.

6.4.1.3 Raw data needs to be converted to a useable file format such as comma delimited (CSV) before it can be viewed or manipulated in other programs (i.e., a spreadsheet program). Data conversion, and file saving procedures are beyond the scope of this SOP and detailed in the SUNACom User Manual (Satlantic 2015) (Pages 61–64).

6.4.2 Data Reprocessing and Correction

6.4.2.1 Data Reprocessing and correction will need to occur prior to statistical analysis of the data. Data reprocessing and correction are complicated procedures that are dependent on many factors and specific characteristics of the data set and correlations with other instruments (e.g., a turbidimeter, flow meter, and temperature probe) deployed at the same site. In general, the data will need to be corrected for fouling and sensor drift, and bias. Procedures for reprocessing and data correction are described in Wagner (2006), Pellarin et. al., (2013) and the SUNACom user manual (Satlantic 2015) on pages 54–60.

7. RECORDS MANAGEMENT

7.1 Squaxin Island Tribe will manage records using Aquarius software that is currently used for continuous flow and temperature data.

8. QUALITY CONTROL AND QUALITY ASSURANCE SECTION

8.1 Squaxin Island Tribe will provide data quality review and conduct corrective actions according to established data management procedures and including additional procedures specified elsewhere in the SOP.

8.2 Specific procedures for calculating quality control metrics including performance, precision, linearity, and method detection limits are described in USGS (2014) Pages 35-37.

9. SAFETY

9.1 Safety is the primary concern when deploying nitrate sensors. Proper fieldwork safety procedures are outlined in the Environmental Assessment Program Safety Manual (Ecology, 2006). A minimum of two people are required when streams are waded. One can deploy the stream nitrate sensor and the other can assist from shore. If stream side hazards such as high flow, weather, and debris make deployment dangerous, then an alternate location, different deployment method, or different deployment time should be considered.

9.2 Nitrate Sensor Specific Safety Concerns

9.2.1 When the instrument is taking a reading it emits UV light which can cause immediate and permanent damage to the eye. It is critical that technicians not look directly at the sensor when the instrument is operational

9.2.2 If it is suspected that the SUNA has flooded, use EXTREME CAUTION around the instrument. The SUNA can operate at depths of up to 500 meters. If the instrument leaked at depth it might remain highly pressurized when recovered and cause the lamp housing or the spectrometer housing to be launched from the coupler with extreme force if the restraining screws are removed.

10. REFERENCES

Ecology, 2012. Environmental Assessment Program Safety Manual. Washington State Department of Ecology, Olympia, Washington.

Ecology. 2009. Quality Assurance Project Plan – Deschutes River Continuous Nitrate Monitoring. Washington State Department of Ecology, Environmental Assessment Program, Olympia Washington. Publication No. 09-03-130. October 2009. Available at: <https://fortress.wa.gov/ecy/publications/publications/1103030.pdf>.

Pellerin, B.A., B.A. Bergamaschi, B.D. Downing, J.F. Saraceno, J.A. Garret, and L.D. Olsen. 2013. Optical Techniques for the Determination of Nitrate in Environmental Waters: Guidelines for Instrument Selection Operation, Deployment, Maintenance, Quality Assurance, and Data Reporting. Techniques and Methods 1-D5. US Geological Survey, Reston, Virginia. Available at: <http://pubs.usgs.gov/tm/01/d5/>.

Satlantic 2014. SUNA User Manual For SUNA running firmware version 2.5 or later. Document: SAT-DN-00628, REV.E December 2014. Satlantic Incorporated, Halifax, Canada. 2014.

Satlantic 2015. SUNACom Manual 3.0.11. Document: SAT-DN-00493-3.0.11-551 Revised April 2015.

Wagner, R.J., R.W. Boulger, Jr., C.J. Oblinger, and B.A. Smith. 2006. Guidelines and Standard Procedures for Continuous Water-Quality Monitors—Station Operation, Record Computation, and Data Reporting. Techniques and Methods 1–D3. US Geological Survey, Reston, Virginia. Available at: <http://pubs.usgs.gov/tm/2006/tm1D3/>.

ATTACHMENT A

General Field Equipment

Sampling Equipment and Supplies

- ______ Calibrated and Programmed SUNA Probe
- ______ Compass
- ______ Maps
- ______ Watch
- ______ Cable Ties
- ______ Chain or Cable
- ______ Wire Cutters
- ______ Knife
- ______ Hand Trimmer
- ______ Survey Flagging

Vehicle/Safety Equipment

- ______ Tire Chains
- ______ Yellow Hazard Beacon
- ______ Flashlight
- ______ Tool Chest
- ______ Jumper Cables
- ______ Flares/Reflectors
- ______ First Aid Kit
- ______ Foil Blanket
- ______ Orange Vests
- ______ 2 Gallons Drinking Water
- ______ Hand Towels

Personal Gear

- ______ Rain Gear
- ______ Knee Boots
- ______ Waders
- ______ Watch/Cell phone
- ______ Gloves
- ______ Extra Clothing
- ______ Hat

APPENDIX C

Turbidity Threshold Sampling Standard Operating Procedure

Washington State Department of Ecology

Environmental Assessment Program

Standard Operating Procedures for Turbidity Threshold Sampling

Version 1.1

Author – Stephanie Estrella
Date – March 2008

Reviewer – William Ehinger
Date -

QA Approval – Bill Kammin, Ecology Quality Assurance Officer
Date -

EAP018

APPROVED: 10/20/10

Signatures on File

Please note that the Washington State Department of Ecology's Standard Operating Procedures (SOPs) are adapted from published methods, or developed by in-house technical and administrative experts. Their primary purpose is for internal Ecology use, although sampling and administrative SOPs may have a wider utility. Our SOPs do not supplant official published methods. Distribution of these SOPs does not constitute an endorsement of a particular procedure or method.

Any reference to specific equipment, manufacturer, or supplies is for descriptive purposes only and does not constitute an endorsement of a particular product or service by the author or by the Department of Ecology.

Although Ecology follows the SOP in most instances, there may be instances in which Ecology uses an alternative methodology, procedure, or process.

SOP Revision History

Revision Date	Rev number	Summary of changes	Sections	Reviser(s)
03/13/2008	1.1	Updated equipment list, summary of procedures, and records management; deleted Figures 2 and 3, added new Figure 2	5.0, 6.0, 7.0, 11.0	S. Estrella

1.0 Purpose and Scope

1.1 This document is for the Environmental Assessment Program Standard Operating Procedure (SOP) for Turbidity Threshold Sampling.

1.2 Turbidity Threshold Sampling (TTS) describes a procedure that uses data from a pressure transducer and an *in situ* turbidity sensor to activate a pump sampler to collect water samples. TTS is used to create a regression model (not covered in this SOP) to relate turbidity with suspended sediment concentrations collected over a range of flow conditions. The regression model can then be used to quantify sediment export from a stream over time or in response to ecosystem disturbances.

2.0 Applicability

2.1 This document was developed as a TTS procedure for the Type N Experimental Buffer Treatment (Type N) Study. The procedure may be applicable for other studies assessing sediment transport in freshwater streams.

3.0 Definitions

3.1 Turbidity Threshold Sampling: a turbidity sampling method using a pressure transducer, *in situ* turbidity sensor, datalogger, and an automatic pump sampler, programmed to activate at a specific turbidity threshold value, to collect water samples during high turbidity events (Lewis 1996; see Appendix A).

3.2 Type N: perennial and seasonal non fish-bearing streams under Washington State's current stream typing system (WAC 222-16-030).

4.0 Personnel Qualifications/Responsibilities

4.1 Knowledge of the contents of this SOP.

5.0 Equipment, Reagents, and Supplies

5.1 Pressure transducer—Ott Messtechnik pressure sensor OTT PS 1 or equivalent
5.2 Electrical conduit pipe, 1.5 inch diameter
5.3 *in situ* turbidity sensor—Forest Technology Systems DTS-12 turbidity sensor or equivalent
5.4 Metal support beams—Unistrut or equivalent
5.5 Pipe and tee connector, 3 inch diameter
5.6 Pipe cement
5.7 Hose clamps
5.8 Wire cable—diameter determined by size of stream

5.9 Cable clamps—size determined by diameter of cable used

5.10 Cable ties

5.11 Suction tubing—tubing diameter determined by pump sampler used; length determined by distance from pump sampler to sampling location in the stream

5.12 Datalogger—Forest Technology Systems HDL1 datalogger or equivalent

5.13 Automatic pump sampler—Teledyne ISCO 6712C portable sampler or equivalent

5.14 Battery—12 volt valve-regulated lead acid battery

5.15 Enclosure—Forest Technology Systems enclosure for Turbidity Threshold Sampling station or equivalent

5.16 Laptop with serial cable interface

5.17 Pump sampler bottles and caps—size determined by pump sampler model used

5.18 Data management software—Forest Technology Systems StreamTrac software or equivalent

6.0 Summary of Procedure

6.1 Install a pressure transducer following the manufacturer's instructions (Ott Messtechnik, nd). The vertical position of the sensor should be the same as that of the flume crest of the streambed. If not, record the offset and adjust the data post-process. Use a conduit or other device to protect the sensor (Figure 1). Secure the apparatus to a stilling well or another stable structure.

6.2 Install an *in situ* turbidity sensor in a pool at the downstream end of the study basin following the manufacturer's instructions (Forest Technology Systems, 2003). Use metal support beams, pipe, tee connector, and hose clamps to suspend the sensor over the stream (Figure 2). Secure the entire apparatus to trees, posts, or another stable structure with wire cable, cable clamps, and cable ties.

6.3 Submerge the open end of the suction tubing in the water near the turbidity sensor (Figure 2).

6.4 Plug the pressure transducer and turbidity sensor into a datalogger (Figure 3). Attach the other end of the suction tubing to an automatic pump sampler. Connect the datalogger to the automatic pump sampler using the provided cables and/or interface. Plug the datalogger and pump sampler into a battery. House the electronic components in an enclosure.

6.5 Program the datalogger using a laptop with a serial cable interface to record stage height and turbidity at specified intervals and to activate the pump sampler at a specified flow and turbidity threshold (see Lewis 1996).

6.6 Program the automatic pump sampler for flow paced sampling (see Lewis 1996).

6.7 Retrieve the samples from the automatic pump sampler following high flow events. Fill the pump sampler with clean pump sampler bottles.

6.8 Submit the samples to the Manchester Environmental Laboratory for suspended sediment concentration analysis. Preserve and ship the samples to the laboratory as described in the laboratory users manual (Manchester Environmental Laboratory 2005).

6.9 Visit the study site periodically to maintain the sensors and tubing, download data, retrieve water samples, and replace batteries. Pressure transducer maintenance includes removing accumulated sediments from the stilling well, re-securing the sensor if needed, and replacing the desiccant in the cable interface. Turbidity sensor maintenance includes replacing wiper blades, removing accumulated sediments from the turbidity sensor pool, and re-securing the sensor and pipe if needed. Pump sampler maintenance includes replacing the pump tube and desiccant annually. Return the pressure transducer to the manufacturer every three to five years and the turbidity sensor once a year for recalibration.

7.0 Records Management

7.1 Maintain data in the StreamTrac database or equilvalent.

8.0 Quality Control and Quality Assurance

8.1 Keep a record of all other sampling activities in the study basin to help explain observed increases in turbidity resulting from sampling activities.

8.2 Ensure that datasheets are completely filled out in the field.

8.3 Check all data entered into the database for accuracy and completeness.

9.0 Safety

9.1 File a field work plan before commencing field activities.

9.2 Use a CB radio to communicate with other traffic on one-way logging roads.

9.3 Learn how to deal with animals and people encountered in remote areas.

10.0 References

10.1 Forest Technology Systems. 2003. DTS-12 SDI Turbidity Sensor Operating Manual, Revision 7. Forest Technology Systems, Victoria, BC. 18 pp.

10.2 Lewis, J. 1996. Turbidity-controlled suspended sediment sampling for runoff-event load estimation. Water Resources Research 32: 2299-2310.

10.3 Manchester Environmental Laboratory. 2005. Lab Users Manual, 8th edition. Environmental Assessment Program, Washington State Department of Ecology, Manchester, WA. 194 pp.+

10.4 Ott Messtechnik. nd. Operating Manual Pressure Sensor OTT PS 1. Ott Messtechnik, Kempten, Germany. 27 pp.

11.0 Figures

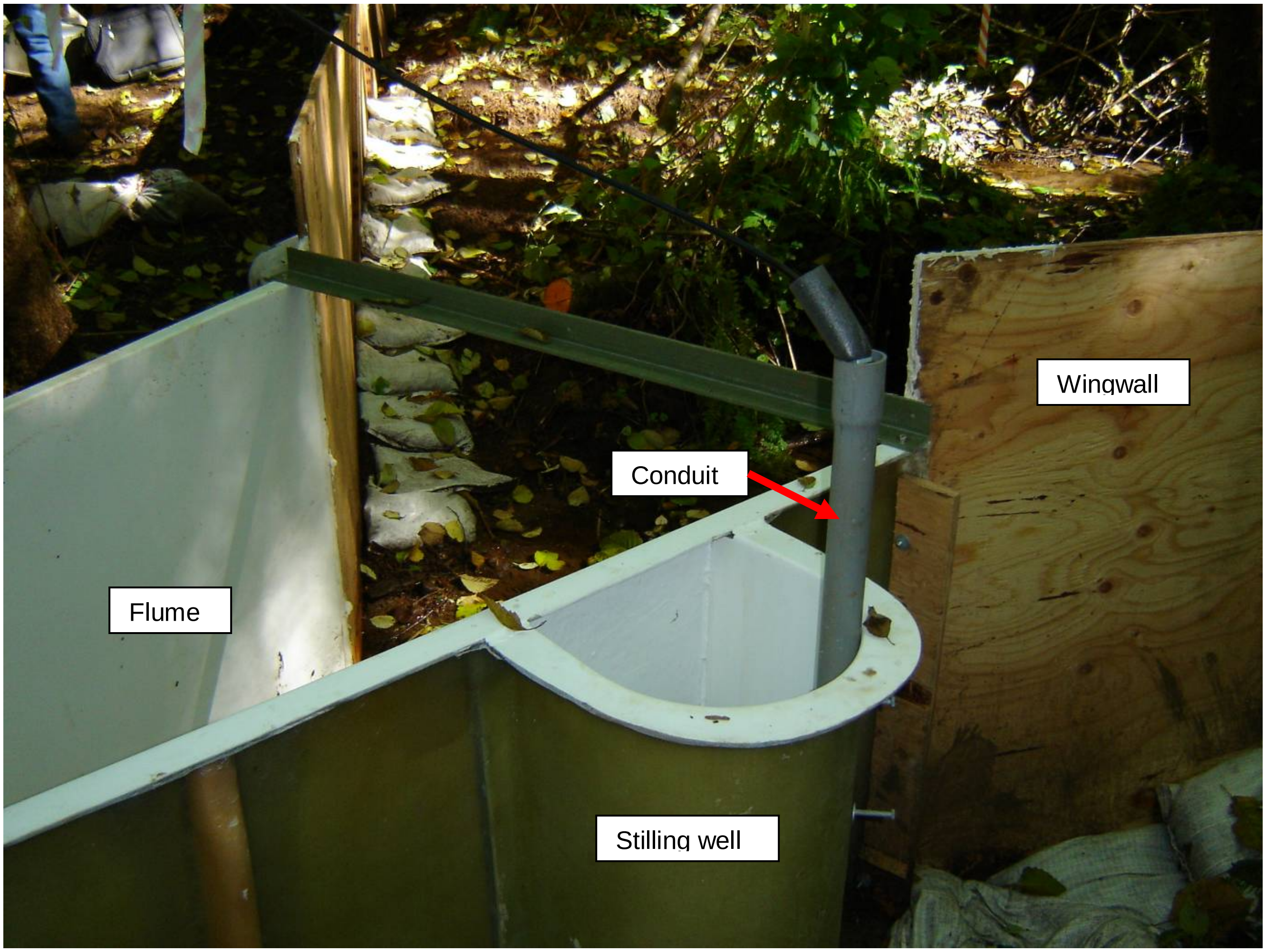

Figure 1. Pressure transducer and conduit in a Type N study stream. Cable ties secure the pressure transducer within the conduit. Holes drilled into the base of the conduit allow water exchange. Bolts secure the conduit to a stilling well and flume.

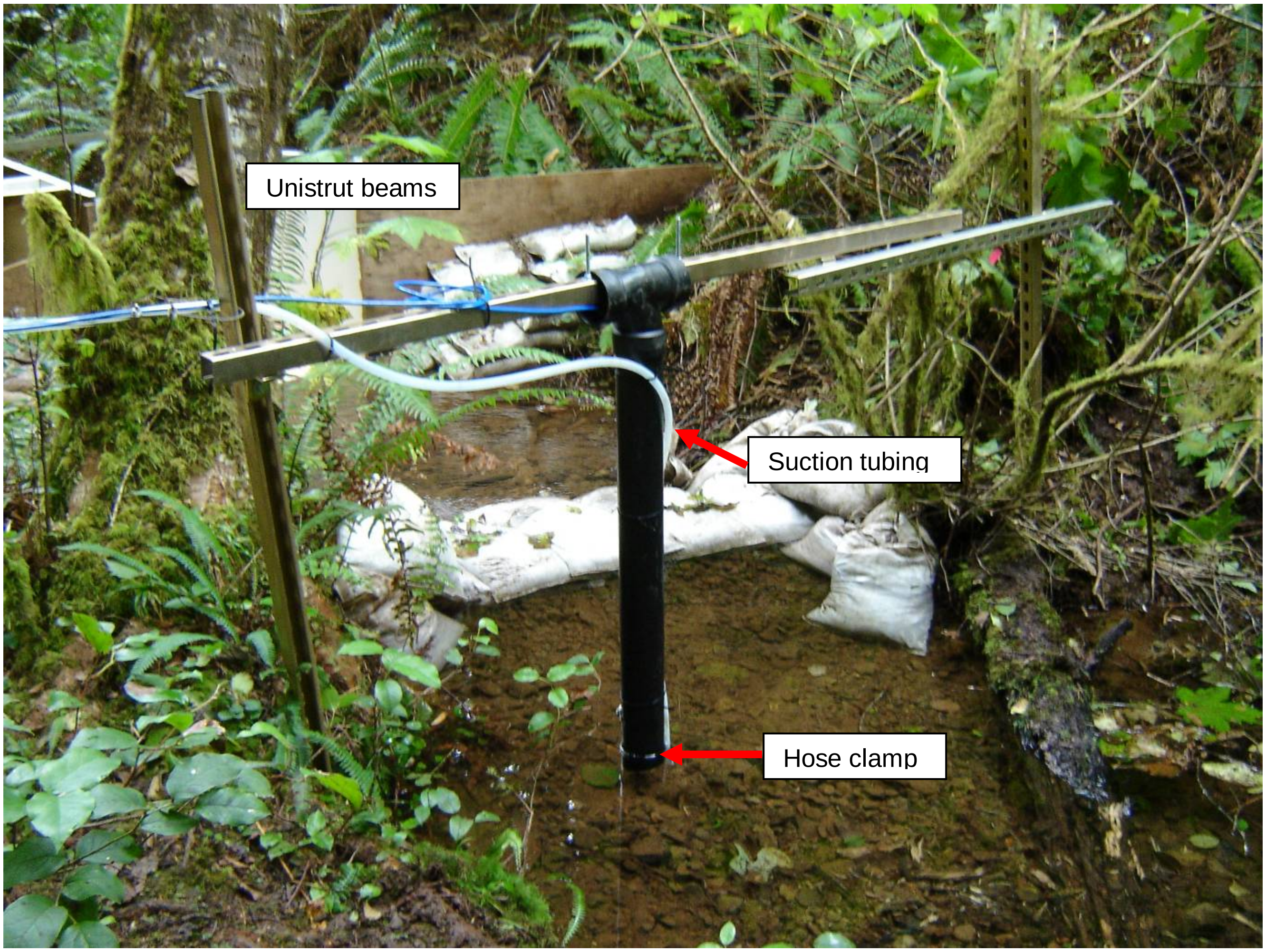

Figure 2. Turbidity sensor apparatus. The turbidity sensor is suspended inside the pipe and secured with hose clamps. The tee connector allows the pipe to move freely with the stream flow. Water is pumped from the stream through the suction tubing and into the pump sampler.

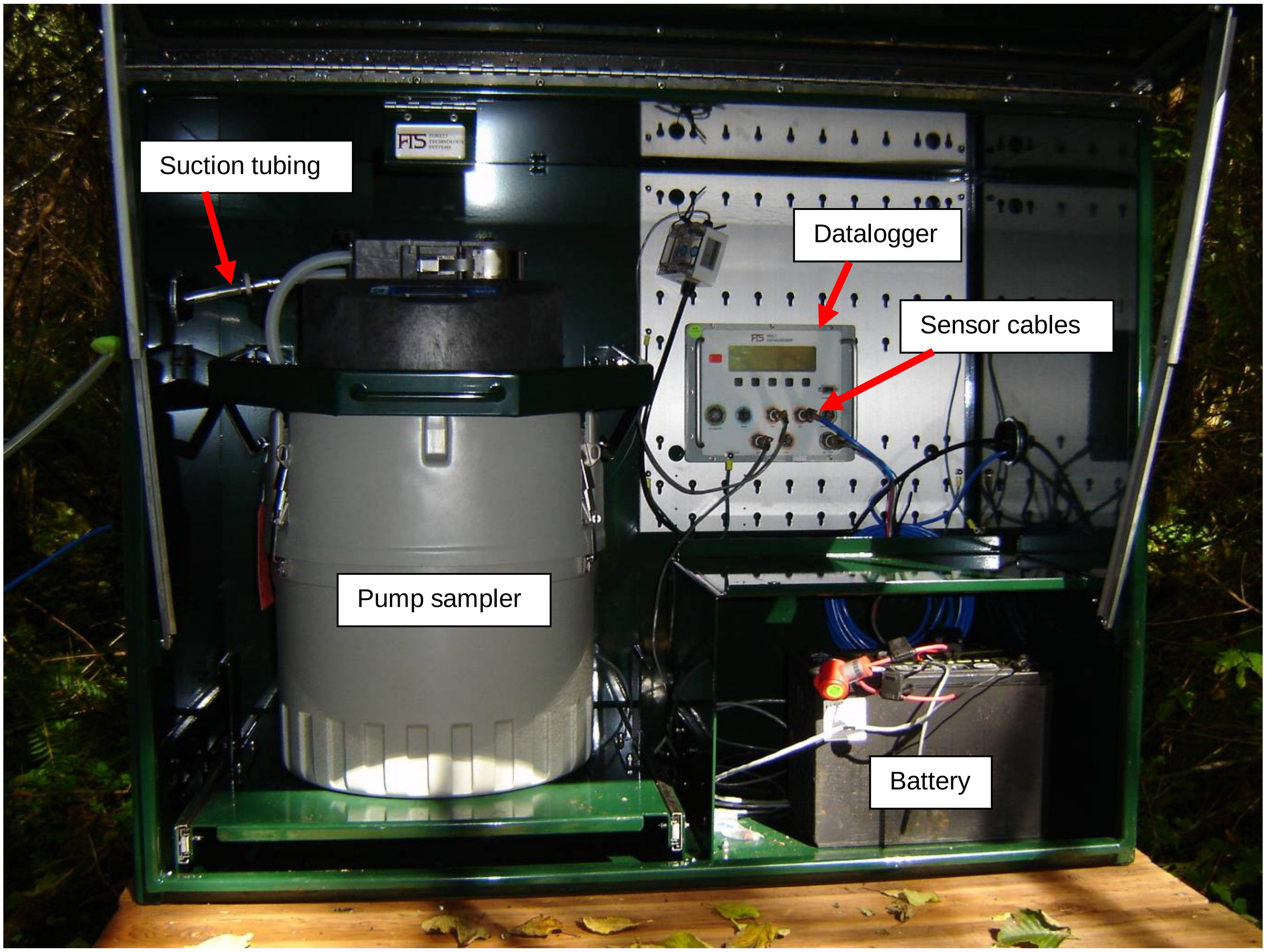

Figure 3. Datalogger and automatic pump sampler with attached components. The datalogger obtains stage height and turbidity readings from the pressure transducer and turbidity sensor at specified intervals. Readings above the specified flow and turbidity threshold trigger the automatic pump sampler to collect a water sample.

12.0 **Appendix A.** Lewis 1996

APPENDIX D

Continuous Temperature Monitoring Standard Operating Procedure

Washington State Department of Ecology

Environmental Assessment Program

Standard Operating Procedures for Continuous Temperature Monitoring of Fresh Water Rivers and Streams.

Version 2.0

Author – William J. Ward
Date –

Reviewers: Dan Sherratt and Dave Hallock

QA Approval - William R. Kammin, Ecology Quality Assurance Officer
Date – 10/26/2011

EAP080

APPROVED: 10/26/2011

Recertified: 2/27/15
Updated and Recertified: 3/25/2015

Signatures on File

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Although Ecology follows the SOP in most cases, we occasionally encounter situations where an alternative methodology, procedure, or process is warranted.

SOP Revision History

Revision Date	Rev number	Summary of changes	Sections	Reviser(s)
4/12/10		First draft updating and incorporating existing 2003 Continuous Temperature Protocols with the 2008 TMDL SOP.	All	W. Ward
		Draft addressing Dan Sherratt and Dave Hallock comments	All	W. Ward
		Draft addressing James Kardouni comments	All	W. Ward
	1.0	Final draft		
10/26/2011	1.0	Editorial cleanup	All	B. Kammin
3/25/15	2.0	Minor editorial updates and recertified	All	W. Ward
3/25/2015	2.0	QA approval	All	B. Kammin

Standard Operating Procedures for Continuous Temperature Monitoring of Fresh Water Rivers and Streams.

1.0 Purpose and Scope

This Standard Operating Procedure (SOP) details a methods used by the Dept. of Ecology (Ecology) to collect continuous temperature monitoring data. It may also contain methods that other entities would find useful for their monitoring work.

The scope of the continuous temperature monitoring program currently focuses on summer (June-September) stream temperatures, but will be expanded to year-round as resources allow.

The intended purpose of the continuous temperature monitoring program is to collect diel stream temperature data that may be used to expand the interpretation of a station's ambient monitoring results and to determine its compliance with state water quality standards. The continuous temperature results are assessed using Ecology's policy for identifying impairments under the federal Clean Water Act (Section 303(d)), which requires stream temperature to be measured on consecutive days in order to apply the criterion.

2.0 Applicability

The Standard Operating Procedures (SOP) will be followed for the installation and maintenance of continuous temperature ambient monitoring stations. These protocols reflect in part those outlined in the TFW Stream Temperature Survey Manual (Schuett-Hames et al., 1999), Continuous Temperature Sampling Protocols for the Environmental Monitoring and Trends Section (https://fortress.wa.gov/ecy/publications/summarypages/0303052.html) (Ward, 2003), Measuring Stream Temperature with Digital Data Loggers (USFS, 2005), and Standard Operating Procedures for continuous temperature monitoring of fresh water rivers and streams conducted in a Total Maximum Daily Load (TMDL) project for stream temperature (Bilhimer and Stohr, 2008).

3.0 Definitions

3.1 7DAD*Max*, 7-day average of the daily maximum temperature

3.2 *EAP*, Ecology's Environmental Assessment Program

3.3 *EIM*, Ecology's Environmental Information Management database for environmental data

3.4 *EPA*, US Environmental Protection Agency

3.5 *GIS*, Geographical Information System

3.6 *GPS*, Global Position System
3.7 *NIST*, National Institute of Standards and Technology
3.8 *PST*, Pacific Standard Time
3.9 *PDT*, Pacific Daylight savings Time
3.10 *QAPP*, Quality Assurance Project Plan

4.0 Personnel Qualifications/Responsibilities

4.1 Field operations require training specified in EAP's Field Safety Manual (Ecology, 2006), such as First Aid, CPR, and Defensive Driving.

4.2 Typical Job Class performing SOP: Natural Resource Scientist 1/2/3, Environmental Engineer 1/2/3/4/5, Environmental Specialist 1/2/3/4/5, Administrative Intern 1/2/3.

5.0 Equipment, Reagents, and Supplies

5.1 *General Field Equipment:*

5.1.1 See Attachment A for a list of the typical equipment and supplies that may be used to deploy temperature loggers.

5.2 *Specialized Field Equipment*[1].

5.2.1 Rebar Pounder (see design specifications in Attachment B)
5.2.2 PVC Shade Device (see design specifications in Attachment B)
5.2.3 Onset Tidbit© v2 Temp Logger, (#UTBI-001), +/- 0.2°C
5.2.4 Onset Hobo© Water Temp Pro v2, (#U22-001), -20°C to +50°C, +/- 0.2C
5.2.5 Onset StowAway Tidbits©, -5°C to +37°C model, +/- 0.2°C
5.2.6 Onset StowAway Tidbits©, -20°C to +50°C model, +/- 0.4°C
5.2.7 Spirit-filled thermometer or long-line thermistor with an accuracy of +/-0.2ºC
5.2.8 PC communication cables or optic shuttles specific for each instrument type

6.0 Summary of Procedure

6.1 *Pre-Deployment Run Preparation*

6.1.1 Assemble equipment. Use a checklist to ensure that all of the necessary preparation tasks, equipment, supplies, and safety gear are completed (See Attachment A for the Continuous Temperature Sampling Checklist).

6.1.2 Calibration Checks. All temperature loggers must be calibration checked both pre- and post-study to document instrument accuracy specifications.

[1] The specialized equipment listed does not represent an endorsement by Ecology. Other equipment may be used if it meets the project QA/QC requirements for accuracy and reliability.

6.1.2.1 The calibration checks are done using test-bath temperatures that bracket the intended monitoring range (near 20 and 0ºC). The bath temperatures must be verified with a NIST traceable or calibrated reference thermistor, thermocouple, or thermometer NIST thermometer)[2]. *Note: This procedure is also used to determine correction factors (if required) for the field thermistor and thermometer measurements.*

6.1.2.2 A calibration-check test-bath method that can maintain a constant temperature is essential to obtain excellent test results. The one described below has worked very well for us. In addition, we have also had great success utilizing a 20-gallon aquarium with a two-bay Hatch Box design and a recirculation pump.

6.1.2.3 Place one open cooler half full of water overnight in a walk-in cooler or room that has a constant air temperature near 0ºC and two coolers (setup similarly) in a room with a temperature near 20ºC. *Note: Test baths done in rooms that have the target temperature ensure stable bath temperatures and the overall quality of the test.*

6.1.2.4 Program the temperature loggers for the test start time and up to a five minute logging interval (a one- to two-minute interval is preferred). String the loggers together to facilitate their transfer into each water bath.

6.1.2.5 Put the programmed temperature loggers in the near 0 ºC test bath overnight.

6.1.2.6 Twenty minutes before the start of the test, place the NIST thermometer in the water bath oriented to easily view the scale increments. Then, gently stir the water to help ensure a uniform water temperature.

6.1.2.7 Gently stir the water bath again a few minutes before test and just after reading and recording the NIST thermometer temperature.

6.1.2.8 Record ten relatively constant and consecutive NIST thermometer comparison measurements on the Calibration Check Form (See Attachment C1 for blank form and Attachment C2 for an example of a used form) when the logger records the water bath temperature. If the logger has a two-minute sampling interval, it may take twenty minutes to obtain the 10 NIST measurements.

6.1.2.9 De-water and transfer the strings of temperature loggers, thermometers, and thermistor probes to one of the room temperature (near 20ºC) water baths. Gently stir the transition water bath and allow the loggers to soak there for several minutes. Then transfer them to the other room temperature water bath for a few minute soak. *Note: this two-step process helps minimize the temperature changes in the final water bath.*

6.1.2.10 Repeat the process noted above to obtain ten relatively constant NIST thermometer comparison measurements the final water bath.

[2] All NIST reference thermistors, thermocouplers and thermometers, used for this test, need to have an annual three-point (near 0, 10, 20°C) calibration check against the Lacey Operations Center NIST or be sent in for an Accredited Calibration Certificate.

6.1.2.11 Download the temperature loggers as soon as possible after the test to shut them off and minimize battery life impacts.

6.1.2.12 Calculate the mean absolute value of the difference between the temperature logger measurements and the NIST thermometer for each water bath with spreadsheet software or by hand. Water-temperature loggers that have a mean difference greater than 0.2°C in one or both water baths have failed the test and cannot be used unless they pass a follow up test.

6.1.3 Launch temperature loggers. Adjust the computer clock settings to Pacific Standard Time (PST) and also make sure that it will not automatically adjust to Daylight Savings Time (DST). Then adjust the clock time to the atomic clock (e.g., http://www.time.gov/). These necessary steps ensure that all the data will be in PST year-round and that all loggers will monitor at exactly the same time.

6.1.4 Program the temperature loggers for a delayed launch that starts at least one hour before the first planned deployment time of the season and at a 30- (or 15-) minute monitoring interval (on the hour and half hour).

6.2 *Stream temperature logger site selection methods*

6.2.1 Deploy temperature loggers in the active and well-mixed part of the stream (or as close as possible to it) to ensure representative temperatures (based on flow volume) are recorded throughout the entire deployment period. The preferred location in these areas is against an instream landmark or other submerged structure that can help hide the logger and minimize the loss to vandalism or high-flow events and also where direct sunlight may be avoided. *Note: avoid deployment locations near popular swimming holes and fishing access points where there is a much higher chance of logger discovery and loss to vandalism.*

6.2.2 Ideal deployment locations are typically at the upstream outside edge or downstream inside edge of the river bends, or in the middle of riffles of low flow and wadeable stream (see Figure 1 below).

6.2.3 Temperature logger locations should never be in eddies or pools or locations where these conditions may develop during low flows. In addition, locations just downstream of tributaries, stream-side wetland areas, point-source discharges, and potential hillside groundwater seeps should also be avoided because these conditions may seasonally bias the recorded temperatures. Consider locations either on the opposite side of the stream or upstream of these conditions.

6.2.4 Deployment depth locations should not be on the stream bottom where the loggers may record groundwater inflow, but deep enough that they do not become exposed to air during a low-flow period. The basic deployment location depth goal is six (6) inches (<0.5 ft) off the stream bottom in smaller streams and wadeable locations and, if possible, at about one half of the water depth in the large streams (Schuett-Hames et al., 1999). *Note: Locating temperature loggers near the stream bottom may be necessary in small streams to ensure that the logger remains submerged during low flows.*

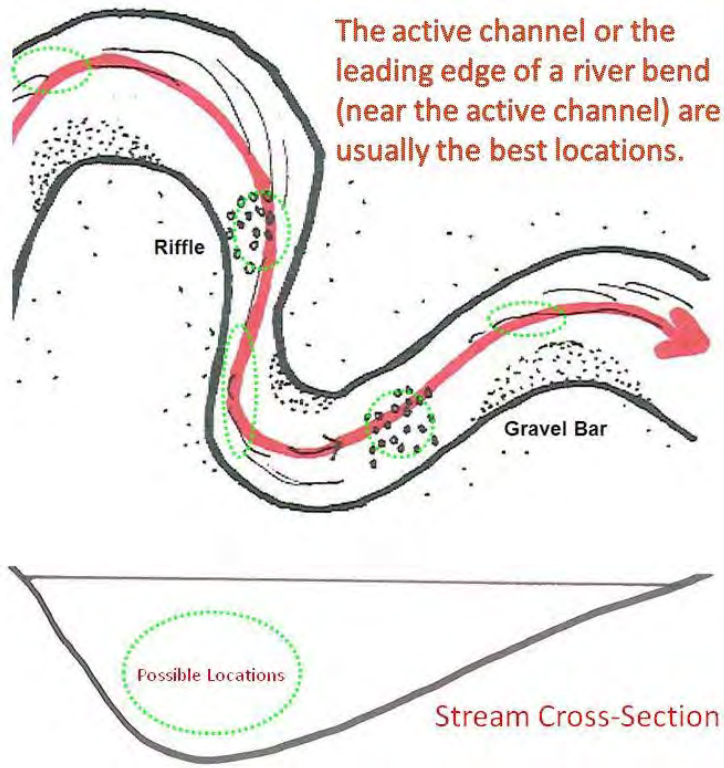


Figure 1. Potential Temperature Logger Deployment Locations

6.2.5 The representativeness of the temperature logger deployment location should be verified by measuring several points in and near the vicinity of the logger and the temperature of the well-mixed part of the stream. If the stream can be easily waded, then a simple cross sectional temperature survey could also be done. Review the survey results, and consider another deployment location, if necessary, to help ensure that the logger will record representative results.

6.3 *Stream temperature logger deployment options*

6.3.1 Record the water-temperature-logger serial numbers on the survey form. (See Attachment D1 for blank form and Attachment D2 for an example).

6.3.2 Pre-assemble the water-temperature logger with a camouflage-painted PVC shade device cover (See fig.2 below and design in Attachment B) that helps hide the logger and prevent any bias from indirect solar radiation.

6.3.3 Avoid low-flow and direct-sunlight temperature logger deployment locations. If the temperature logger needs to be deployed in these locations, then a white PVC shade cover must be used to prevent any solar-biased temperature results (USFS, 2005).

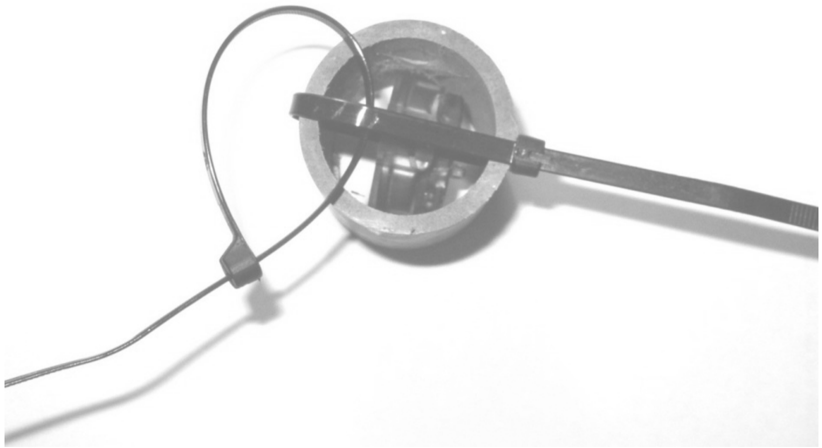


Figure 2. Assembled Temperature Logger and PVC Cover

6.3.4 Place a thermometer or thermistor as close as possible to the identified deployment location and record the measurement after the logger has been deployed. Consider one the use of one of the following deployment methods:

6.3.5 Rebar Deployments. This option is typically used in small- and medium-sized streams to create a suitable temperature logger attachment location in or as near as possible to the active part of the stream. In most cases, this method is best used against the active-part-of-the-stream side of a large landmark rock or log.

6.3.6 Choose a 2-3 foot length of rebar that can be driven deep enough into the streambed to stay in place during high streamflow events and provide an attachment location that is six inches to one-half of the expected total stream depth during the seasonal low-flow period.

6.3.7 Insert the rebar into the open end of the rebar pounder and use a 4# engineering hammer (or an alternative) to hammer the rebar into the streambed by striking the heavy steel head of the pounder. Hammer all but eight inches of the rebar into the streambed[3].

6.3.8 Leave the rebar pounder on the rebar, and document the water-temperature logger location with photographs.

6.3.9 Remove the rebar pounder and attach the temperature logger assembly to the rebar about 6 inches off the bottom (or mid-water depth) with a cable tie. *Note: In fast-flowing locations an additional cable tie should be attached to the rebar just above the temperature logger assembly attachment point to prevent its loss should the second cable tie loosen on the rebar (or attach the assembly using a small gage wire).*

[3] If a mid-stream depth is desired, then leave more rebar exposed.

6.3.10 Large Rock, Tree Root, or woody debris deployments. This option uses existing instream structures such as large rocks or boulders, woody debris, or roots that are located in or extend into the desired location in the active part of the stream. Attach the water-temperature logger to these structures with cable ties or wire, or to cable or heavy wire that may be used to create the location near the base of these structures.

6.3.11 Photographs of the location using a visual marker (such as the rebar pounder, hammer handle, nearby flagging, or pointing with a finger) are essential to help relocate loggers installed by this method.

6.3.12 Anchor deployments. This option can be used where stable large woody debris is not available or where near-surface bedrock or other consolidated sediments prohibit rebar use. The basic approach is to attach the water-temperature-logger assembly to a heavy weight (i.e., rock, brick, concrete block, wadded up piece of chain, or rebar) that may be set in the desired water-temperature-logger location.

6.3.13 It is also advisable that the heavy object be cabled or chained to something on the nearest bank (or other stable instream structure) to prevent loss during a possible high flow event (*Note: rusty chain use may deter logger loss to vandalism more than a shiny cable*). The heavy weight may be encouraged into the desired deployment location using a stick or boat hook (or similar device). *Note: this is not considered a viable option in locations with a significant groundwater inflow*.

6.3.14 Streamside or pile deployments. A long protective PVC or metal pipe housing may be used to establish a deployment location along deep rivers or at wildly fluctuating streams. The pipe can be fastened to a piling, pier, or anchored to large rocks and trees on the stream bank with the lower end extended into the active part of the stream. The upper end of the pipe should be secured with a threaded or locking cap to discourage casual vandalism. The lower end of the pipe should be perforated to allow streamflow around the logger and also be blocked with a diagonal bolt (or similar device) to prevent logger loss out that end. The logger in a protective cover needs to be kept at the lower pipe end with a weighted cord, length of PVC pipe, or any other method that also allows retrievals and deployments to be made through the upper capped end (see figure 3 example below).

6.3.15 Buoy or dock deployments. This option may be useful where no pilings are available or where a string of thermistors is desired to monitor stratified conditions. One issue with this type of deployment option is the high vandalism potential. This potential increases dramatically when establishing a new floating structure, so it is best to use existing structures if permission can be obtained.

6.3.16 Aquatic Invasive Species. Clean all field equipment that contacted water following procedures in Parsons, et al., (EAP070) and Ward, et al., (EAP071).

Figure 3. Deployment method using a length of PVC pipe

6.4 *Air temperature logger deployment methods*

6.4.1 Use temperature loggers that can record the maximum expected temperature for the deployment location. If you are locating loggers in an area where the summer air temperatures can exceed 100ºF (37ºC), then use an air thermistor that has the higher temperature range setting.

6.4.2 Record the air-temperature-logger serial numbers on the survey form.

6.4.3 Pre-assemble the air-temperature logger with a PVC shade device cover. The pre-assembly should be done before beginning the process to install the logger (See Figure 2 above).

6.4.4 These temperature loggers need to be located within the same microclimate of the water logger. Ideal locations are 1-3 meters into the riparian zone (Schuett-Hames and others, 1999) and about 4-8 feet above the ground (USFS, 2005). Avoid placing them in areas that are not representative of streamside conditions at your location or where they will be severely impacted from solar radiation. The north side of a shrub or tree trunk should work well in most locations, especially those with limited streamside vegetation choices[4].

6.4.5 One air-temperature logger should be deployed near every water-temperature-logger location. However, if the vegetation and streamside conditions are similar, then one air-temperature logger may be used to cover several nearby water-temperature loggers. *Note: Air loggers deployed for Total Maximum Dailey Load studies (*Bilhimer and Stohr, 2008) *must be within approximately 0.5 mile of the most distant water logger*.

[4] Do not use weeping willows, as they can secrete fluid during hot weather and create error in the air temperature results.

6.5 *Documentation Procedures*

6.5.1 Record all the field data and deployment location information on the Continuous Temperature Station Survey Form (See example in Attachment D-1) or by a similar method. Be sure to note the station number and name, temperature logger ID numbers, and air- and water-temperature measurements, and any other useful narrative observations, especially those useful for finding the location (e.g. – "upstream of largest boulder on right bank").

6.5.2 Also, record all observation times in PST (or note when they are DST, so they may be converted to PST later), and use a timepiece that has been calibrated to the atomic clock (or use the cell-phone time).

6.5.3 Further, draw a map and describe the general area, noting the temperature-logger locations, logger installation technique, and any landmark references such as a unique rock, log, root, flagging, or tree (See example in Attachment D-2). *Note: if possible, draw the map with north being toward the page top or denote the direction of north on the drawing*.

6.5.4 Take upstream and downstream photographs of the water-temperature-logger location that includes some visual marker (such as the rebar pounder, hammer handle, or pointing with a finger) to use along with the information on the survey form to help relocate and retrieve it in the future (See Fig 4 below). In addition, a nearby tree can also be noted as a useful landmark.

6.5.5 Measure and record: the total water depth (water depth), distance from the logger to the streambed (height), distance from water surface to the logger (deployment depth), and the stream temperature on the survey form.

Figure 4. Photo showing the water-temperature-logger deployment location.

6.5.6 Record the temperature logger GPS coordinate location (or note the logger location on an accurate map and determine the coordinates later).

6.6 *Mid-deployment checks*

6.6.1 If possible, periodically visit the temperature-logger location during the deployment period to get mid-deployment temperature-check data and to make sure that it remains submerged and in a representative location. If the logger needs to be moved or is missing and needs to be replaced, then take the appropriate action and enter new remarks and notes on the survey form. *Note: consider taking replacement loggers and deployment equipment along when doing these checks to help expedite to process.*

6.7 *Retrieval Procedures*

6.7.1 Measure and record the stream temperature and surface depth of the water-temperature logger (retrieval depth), and record the results on the field form. Also, measure and record the distance from the streambed up to the logger, and note any differences between the result and what was recorded during deployment.

6.7.2 If the stream may be easily waded, then also consider doing a cross-sectional survey of the stream temperature. The survey results may help determine if the stream-temperature logger measured representative temperatures and show any cross-sectional temperature differences.

6.7.3 Remove all rebar, cement blocks, or other deployed equipment at the end of the study.

6.7.4 Aquatic Invasive Species. Clean all field equipment that contacted water following the procedures in Hallock, et al., 2010 (EAP070) .

6.8 *Downloading Procedures*

6.8.1 Gently clean the temperature loggers with a soft wet cloth to remove any biofouling or sediment that may affect its ability to communicate optically during the downloading process. The preferred method is to use water and a soft cloth or soft-bristled brush. Note: avoid using any method that can scratch the logger optic communication area.

6.8.2 Set the computer clock to atomic clock time for the Pacific Time Zone before downloading any temperature loggers. Then follow the manufacturer's downloading procedures, and save the data in text files that may be opened in Excel or another type of spreadsheet software.

7.0 Records Management

7.1 Continuous Temperature Survey Forms are used to document the deployment and retrieval information for a station. Filled-out field forms are organized and stored in binders to use for long-term recordkeeping.

7.2 Use Ecology's FMU Access® Data Logger Database developed by Dave Hallock, to manage, store, export, and upload data summaries to Ecology's Environmental Information Management System (EIM). *Note: the database is available to interested agencies and organizations upon request.*

8. 0 Quality Control and Quality Assurance Section

8.1 *Temperature Logger Post-Deployment Accuracy Check.* Verify the accuracy of the retrieved temperature loggers by conducting a post-deployment calibration check (Refer to Calibration Check procedure, 6.1.2, above).

8.1.1 If the mean absolute value of the temperature difference for a logger in each water bath, compared against the NIST certified thermometer, is equal to or less than the manufacturer stated accuracy (i.e. usually ±0.2°C for a water-temperature logger or ±0.4°C for an air temperature logger), then a second check should be performed.

8.1.2 If a second calibration check result confirms a consistent bias above the stated accuracy, then the raw data should be adjusted by the mean difference of the pre- and post-calibration check results to correct for the logger bias (Schuett-Hames et al., 1999).

8.2 *Data Proofing Procedures.* Data from temperature loggers that met the calibration-check accuracy requirement are proofed and QC checked using *Ecology's FMU Access® Data* Logger Database. This database allows the information recorded on the Continuous Temperature Data Report Form (deployment/retrieval times and temperatures) and available climatic and flow data to be used to proof, edit, run automated QC checks, store, summarize, report, and export the finalized data (to text files, Microsoft® Excel, or to Ecology's Environmental Information Management (EIM) system Excel template).

8.2.1 *Note: all identified anomalous data may be omitted from the data set, provided that the justification remark(s) is inserted on the station Continuous Temperature Station Survey Form and in the electronic record for the data. Similarly, all explainable climatic caused data spikes (i.e. - rain events) should also be noted in these same two records.*

8.2.2 All data will be assigned a measurement accuracy value based on the pre- and post-deployment calibration check results.

9.0 Safety

Safety is the primary concern when deploying temperature loggers. Proper fieldwork safety procedures are outlined in the Environmental Assessment Program Safety Manual (Ecology, 2012). A minimum of two people are required when streams are waded. One can deploy the stream temperature loggers and the other can assist from shore. If streamside hazards such as high flow, weather, and debris make the temperature logger deployment dangerous, then an alternate location, different deployment method, or different deployment time should be considered.

10.0 References

10.1. Bilhimer, D. and Stohr, A., 2008. Standard Operating Procedures for Continuous Temperature Monitoring of Freshwater Rivers and Streams Conducted in a Total Maximum Daily Load (TMDL) Project for Stream Temperature, Version 2.2. Washington State Department of Ecology, SOP Number EAP044. http://www.ecy.wa.gov/programs/eap/qa/docs/ECY_EAP_SOP_Cont_Temp_Monit_TMDL_v3_0EAP044.pdf.

10.2. Dunham J., G. Chandler, B. Rieman, and D. Martin, 2005. Measuring Stream Temperature with Digital Data Loggers: A User's Guide. U.S.D.A. Forest Service Rocky Mountain Research Station. General Technical Report RMRS-GTR-150WWW. 16 p.

10.3. Environmental Assessment Program, 2012. Environmental Assessment Program Safety Manual.

10.4. Hallock, D. 2010. Standard Operating Procedures to Minimize the Spread of Invasive Species from Areas of Extreme Concern. EAP_SOP070.

10.5. Schuett-Hames, D., A. E. Pleus, E. Rashin, and J. Matthews, 1999. TFW Monitoring Program Method Manual for the Stream Temperature Survey. Washington State Department of Natural Resources and NW Indian Fisheries Commission publication #TFW-AM9-99-005.

10.6. Ward, W., 2003. Continuous Temperature Sampling Protocols for the Environmental Monitoring and Trends Section. Washington State Department of Ecology, Olympia, WA. https://fortress.wa.gov/ecy/publications/summarypages/0303052.html.

Attachment A

This Attachment contains the checklist used to prepare for temperature logger deployments.

Continuous Temperature Sampling Checklist

Pre-Deployment Preparation

_____ Determine Number of Stations
_____ Determine Deployment Equipment Needs
_____ Obtain or Make Deployment Equipment
_____ Check Calibration of:
_____ • Temperature Loggers
_____ • Thermometer
_____ • Thermistor
_____ Plan Deployment Schedule
_____ Schedule Field Assistance
_____ Program Temperature Loggers
_____ Make Motel Reservations
_____ Fill out Field Work Plan and Contact Person Designation Form
_____ Gas Van

Van/Safety Equipment

_____ Tire Chains
_____ Yellow Hazard Beacon
_____ Flashlight
_____ Tool Chest
_____ Jumper Cables
_____ Flares/Reflectors
_____ First Aid Kit
_____ Foil Blanket
_____ Orange Vests
_____ 2 Gallons Drinking Water
_____ Hand Towels
_____
_____

Sampling Equipment and Supplies

_____ Programmed Temperature Loggers
_____ Continuous Temperature Survey Forms
_____ Thermometer
_____ Thermistor
_____ Compass
_____ Maps
_____ Watch
_____ Camouflaged PVC Pipe
_____ Cable Ties
_____ Rebar Pounder
_____ 3/8 inch x 2 – 3 Ft. Rebar Pieces
_____ 4# Hammer
_____ Several lengths of Chain or cable
_____ Pyramid Blocks
_____ Small Wire Cutters
_____ 6’ Pole W/Hook
_____ Knife
_____ Hand Trimmer
_____ Machete
_____ Survey Flagging
_____ Digital Camera
_____ Duct Tape

Personal Gear

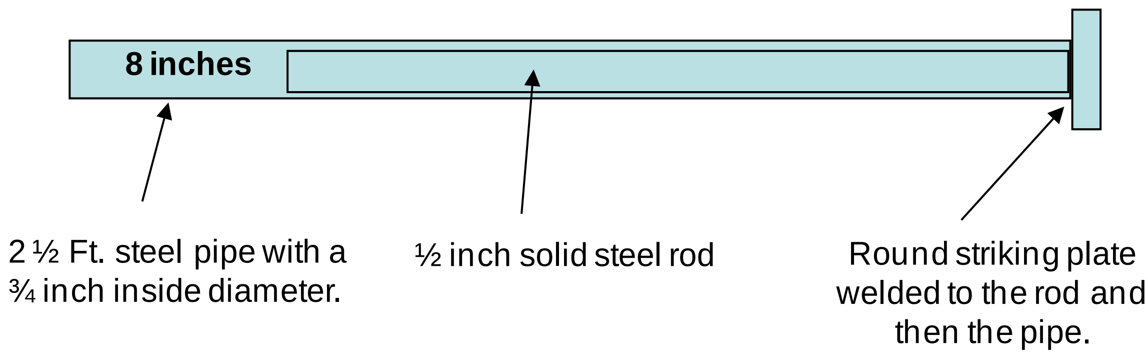
_____ Rain Gear
_____ Knee Boots
_____ Waders
_____ Watch
_____ Gloves
_____ Extra Clothing
_____ Hat
_____
_____
_____

Attachment B

This attachment contains the design specifications for the equipment that is made “in-house.” These designs have been created to meet specific needs for past field studies and can be modified as needed. The equipment to make these includes: power saws, drill press, and other hand tools. The rebar pounder is manufactured by a contracted welder.

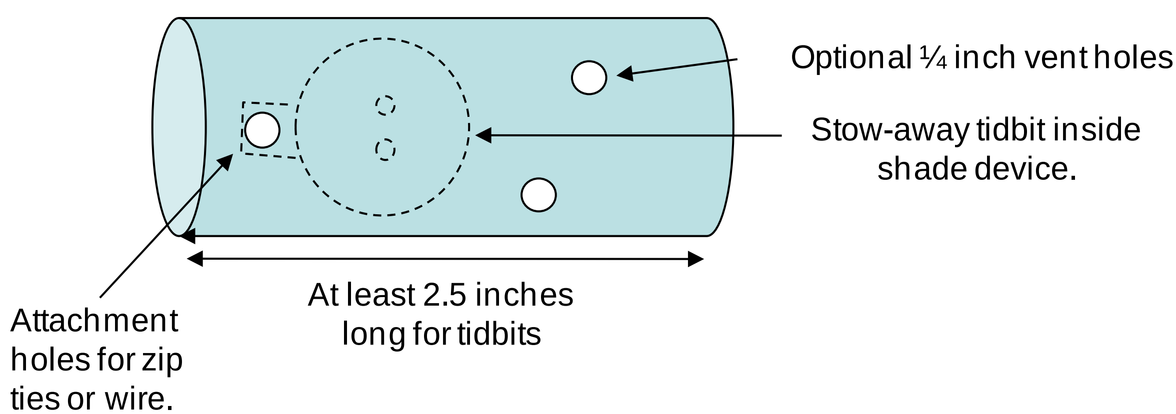
Rebar Pounder Design

Used to drive #4 (½ inch) rebar sections (2-4ft in length) into the streambed to establish an instream thermistor attachment location. The rebar is inserted in the hollow end and a heavy hammer is used to pound on the striking plate.

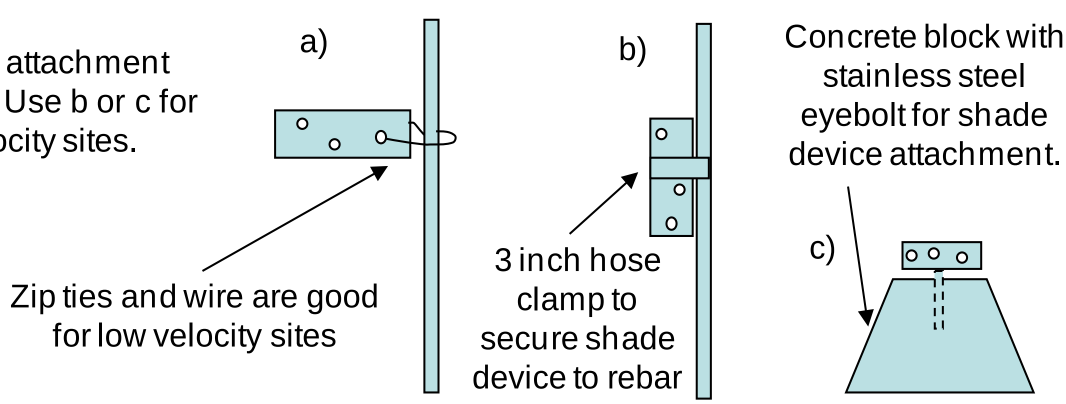


PVC Shade Device

This is typically made from 1.5 inch (inside diameter) PVC pipe. It should completely cover the thermistor to prevent solar radiation absorption. This design may be used for both instream and air thermistors.



Possible attachment options. Use b or c for high velocity sites.



Attachment C .

C-1. Temperature Logger Calibration Check Form – Blank Form.

C-2. Temperature Logger Calibration Check Form - Filled Out Form.

C-1. Temperature Logger Calibration Check Form – Blank Form.

Date: __________

Temperature Logger Calibration Check Form

Technicians:

____

	Time	NIST SN-	Thermistor #	Red Liquid SN-	SN-	SN-
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						
15						

	Time	NIST SN-	Thermistor #	Red Liquid SN-	SN-	SN-
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						
15						

C-2. Temperature Logger Calibration Check Form - Filled Out Form.

Date: 5/4/09

Temperature Logger Calibration Check Form

Technicians: WARD

	Time	NIST SN- 70409	Thermistor # SLLT-1	Red Liquid SN- 8N935	RED LIQUID SN- 8N911	SN-
1	08:30	4.3	4.2	4.3	4.3	
2	:32	4.3	4.2	4.3	4.3	
3	:34	4.3	4.2	4.3	4.3	
4	:36	4.3	4.2	4.3	4.3	
5	:38	4.3	4.2	4.3	4.3	
6	:40	4.3	4.2	4.3	4.3	
7	:42	4.3	4.2	4.3	4.3	
8	:44	4.3	4.2	4.3	4.3	
9	:46	4.3	4.2	4.3	4.3	
10	:48	4.3	4.2	4.3	4.3	
11	:50	4.3	4.2	4.3	4.3	
12	:52					
13						
14						
15						

	Time	NIST SN- 70409	Thermistor # SLLT-1	Red Liquid SN- 8N935	RED LIQUID SN- 8N911	SN-
1	09:14	21.0	21.0	21.0	20.9	
2	09:16	21.05	21.0	21.1	20.9	
3	:18	21.1	21.1	21.1	21.0	
4	:20	21.1	21.1	21.1	21.0	
5	:22	21.1	21.1	21.1	21.0	
6	:24	21.1	21.1	21.1	21.0	
7	:26	21.1	21.1	21.1	21.0	
8	:28	21.1	21.1	21.1	21.0	
9	:30	21.1	21.1	21.1	21.0	
10	:32	21.1	21.1	21.1	21.0	
11	:34	21.1	21.1	21.1	21.0	
12	:36	21.1	21.1	21.1	21.1	
13						
14						
15						

GOOD

Attachment D

This section contains a blank and filled out example of the Continuous Temperature Survey Form that should be used for Ambient Monitoring - continuous temperature logger deployments. The form must be printed on waterproof paper and all completed ones need to be organized and stored in binders for archival purposes.

D-1. Blank Survey Form

D-2. Filled-out Survey Form

D-1. Blank Survey Form

Continuous Temperature Survey Form

Station #: ___________ **Station Name:** ___________________________ **Samplers:** _______________________

Interval Frequency 00:30

Water Temperature Logger

I.D. # ________________

Water Depth ______ **ft** **Deployment Depth** ______ **ft**

Height (Abv Bottom) ______ **ft** **Retrieval Depth** ______ **ft**

Air Temperature Logger

I.D. # ________________

Height (Abv Stream) ______ **ft**

Date	Time	Water Temp	Air Temp	Weather/ Comments

Air Temperature Logger Location:

Water Temperature Logger Location:

D-2. Filled-out Survey Form

Continuous Temperature Survey Form

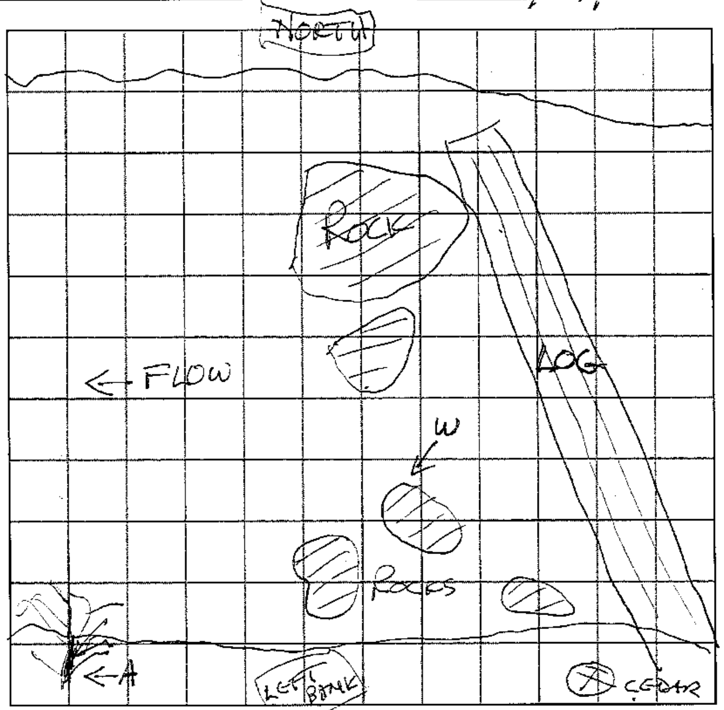
Station #: 08C110 **Station Name:** CEDAR NR LANDSBURG **Samplers:** WARD/MYERS

Interval Frequency 00:30

Water Temperature Logger
I.D. # 457373
Water Depth 1.5 **ft** **Deployment Depth** 1.0 **ft**
Height (Abv Bottom) 0.5 **ft** **Retrieval Depth** 0.7 **ft**

Air Temperature Logger
I.D. # 457375
Height (Abv Stream) 6 **ft**

Date	Time	Water Temp	Air Temp	Weather/ Comments
6/25	11:40	11.8	12.5	OVERCAST
9/24	10:20	12.3	·	PARTLY SUNNY



Air Temperature Logger Location:
ON VINE MAPLE ~ 3.5' OFF GROUND, TREE IS LOCATED ~ 15' DOWNSTREAM OF WATER LOGGER LOCATION (ORANGE FLAGGING). LOGGER IS ON BANK SIDE OF TREE.

Water Temperature Logger Location: ON REBAR INSTALLED ON THE STREAM/UPSTREAM CORNER OF THE FIRST OF TWO LARGE ROCKS (> 3.5' DIAMETER) BELOW LARGE LOG (~ 9' FROM LOG). NEAR LEFT BANK.

APPENDIX E

Stream Gauge and Discharge Monitoring Standard Operating Procedures

Washington State Department of Ecology

Environmental Assessment Program

Standard Operating Procedure for Measuring Gage Height of Streams

Version 1.1

Author – James R. Shedd
Date – 08/29/2008

Reviewer – Don Watt
Date – 09/22/2008

QA Approval - William R. Kammin, Ecology Quality Assurance Officer
Date – 10/07/2008

EAP042

APPROVED: October 7, 2008
RECERTIFIED: August 10, 2015

SIGNATURES ON FILE

Please note that the Washington State Department of Ecology's Standard Operating Procedures (SOPs) are adapted from published methods, or developed by in-house technical and administrative experts. Their primary purpose is for internal Ecology use, although sampling and administrative SOPs may have a wider utility. Our SOPs do not supplant official published methods. Distribution of these SOPs does not constitute an endorsement of a particular procedure or method.

Any reference to specific equipment, manufacturer, or supplies is for descriptive purposes only and does not constitute an endorsement of a particular product or service by the author or by the Department of Ecology.

Although Ecology follows the SOP in most instances, there may be instances in which Ecology uses an alternative methodology, procedure, or process.

SOP Revision History

Revision Date	Rev number	Summary of changes	Sections	Reviser(s)
08/10/2015	1.1	Updated reference and link to EAP Safety Manual	9.0	Jim Shedd
08/10/2015	1.1	Made grammatical and formatting adjustments, rephrased language throughout document.		Jim Shedd

1.0 Purpose and Scope

1.1 This document is the Environmental Assessment Program (EAP) Standard Operating Procedure (SOP) for determining the stage of a stream using a staff gage, wire weight gage, laser level, weighted measuring tape (tape down), and crest stage gage.

2.0 Applicability

This procedure is followed when determining or verifying the gage height or relative water surface elevation of a stream.

3.0 Definitions

3.1 Stage/Water Surface Elevation/Gage Height — Stage is the confirmed water surface elevation above a datum. Gage height is the water surface reading on a particular gage (Rantz et al., 1975). Most Stream Hydrology stations use an arbitrary zero datum.

3.2 Primary Gage Index — The primary gage index is the base gage for the station, directly referenced to the recording gage. The primary gage index is the most stable and reliable gage at a site. All other gages at a station are considered secondary gage indexes.

3.3 Secondary Gage Index — Secondary gage indexes are used to confirm the primary gage index. The secondary gage is used to estimate the value of the primary gage if the primary gage is damaged or missing.

3.4 Recording Gage — Typically, an automated bubbler or pressure transducer measures and records the stage to an electronic data logger maintaining a continuous record of stage through a specified period of time. The bubbler or transducer is calibrated to match the primary gage index.

3.5 Reference Mark — A reference mark is a permanent marker of known elevation above the zero datum, installed in the ground or on a stable structure in the vicinity of the gauging station.

3.6 Reference Point — A reference point is a marker above the zero datum from which the water surface elevation can be determined by measuring down to the water surface.

3.7 Zero Datum — Zero datum is an arbitrary plane below the elevation of zero flow and maximum scour on a control.

3.8 Laser Beam Elevation — Laser beam elevation is the elevation of the plane of the laser emitted by the laser instrument.

3.9 Differential — Differential is the difference in elevation between the laser rod reading and the water surface rod reading.

Control — The physical features of a stream that control the relationship between stage and discharge at a gage site.

3.10 Point of Zero Flow — Stage at which water ceases to flow over the control. The point of zero flow is the lowest point on the control

4.0 Personnel Qualifications/Responsibilities

4.1 Personnel using this SOP should have training and field experience in making stream gage site visits, recording and documenting pertinent data.

5.0 Equipment, Reagents, and Supplies

5.1 Copies of the standard Ecology field forms (Attachment A) for recording times, gage readings, and actions taken while at the gage site are kept in a suitable field notebook. These forms are usually printed on Rite in the Rain™ paper for outdoor durability.

5.2 A stadia rod is used to determine the difference in elevation between the water surface and laser level beam.

5.3 A circular bubble level is attached to the stadia rod to ensure rod is held vertically.

5.4 A laser level instrument emits a laser beam illuminating a horizontal plane of known elevation. The laser beam elevation is used to determine water surface elevation.

5.5 An engineer's tape measure is used to measure the high water mark on a crest stage gage.

5.6 A weighted measuring tape is used for measuring a tapedown to the water surface from a reference point.

6.0 Summary of Procedure

6.1 Establishing Gage Datum — The stage or water surface elevation at a stream gauging site and the elevations of all reference marks, reference points, and gages used to determine stage are relative to a common datum. At most stations, a zero datum is arbitrarily assigned corresponding to the elevation of the primary gage index. Primary gages are installed such that the assumed zero point of the primary gage is below the point of zero flow and expected scour of the control.

6.1.1 Movement of the structures supporting the primary gage disturbs the datum. Periodic leveling surveys (levels) check the relative position of the primary gage against reference marks of known elevation.

6.1.2 Levels are run at a minimum of every 3 years or as soon as possible when unresolved discrepancies between gage observations or movement of gage structures, reference marks, or reference points are suspected.

6.1.3 When the primary gage has moved, the gage is recalibrated to the datum and/or relocated to the proper elevation when possible.

6.1.4 In some applications, relocation of the gage is not possible. The ways in which these circumstances are handled are presented in the following discussions of each type of gage.

6.2 Placement of Gages — Primary and secondary gages are placed in the gage pool subject to the same station control and as close in proximity as possible to the recording gage.

6.2.1 Gages are not placed in a stream section regulated by different controls, as channel dynamics and geometry are not the same. Stage fluctuates at different rates and magnitudes, relative to changes in discharge.

6.3 Determining Stage Height by Observing a Staff Gage — A vertical standing staff gage is a singular or a successive series of porcelain enameled steel plates mounted to a secure structure. Most staff plates used by the Washington State Department of Ecology are graduated in 0.02 feet increments. Staff gage observations are recorded to 0.01 feet resolution.

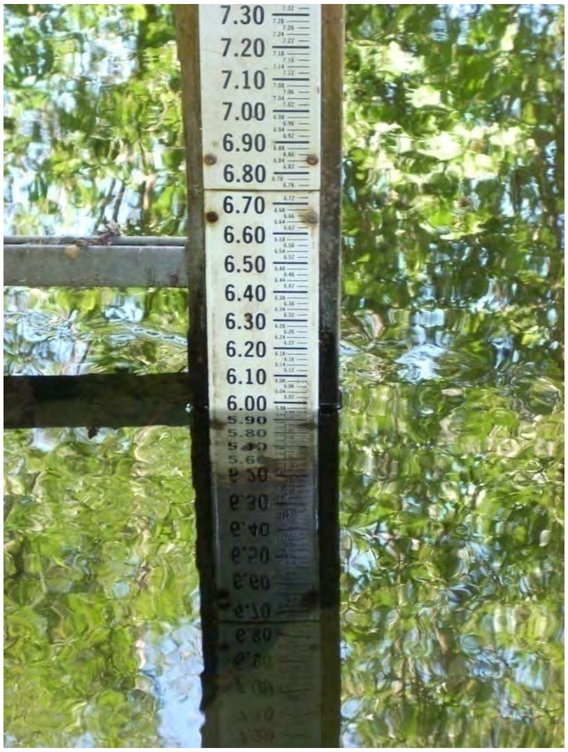


Figure 1 A typical Ecology staff gage with 0.02 feet increments. (Photo by Washington Dept. of Ecology)

6.3.1 In many locations, the water level may surge against the staff gage structure, causing the water surface to fluctuate or bounce on the staff gage. If the water level fluctuates on the staff, read the average level and note the reading with the range of water level fluctuation (uncertainty) i.e. 4.16 +/-0.04, where 4.16 is the average of the peaks and troughs of the waves and +/- 0.04 is the range of the peaks and troughs.

6.3.2 In situations where the fluctuation is excessive or significant velocity head builds-up on the staff gage structure, use a makeshift stilling well. A good makeshift stilling well consists of a 5-gallon bucket with the bottom cut out and a cut up the side to permit spreading of the bucket walls to surround the staff gage structure. Open the bucket walls and wrap around the staff gage with the bottom of the bucket walls at a depth of 0.5 to 1 feet. This should calm the water around the staff gage enough to obtain a more reliable reading.

6.3.3 Take the necessary time to obtain the most accurate observation. Record the uncertainty of the observation for future analysis.

6.3.4 Record the date, time, the staff gage observation and the uncertainty on the field site visit form or appropriate discharge measurement form.

6.3.5 In situations when the staff gage elevation has changed, reposition the staff plate to the original elevation.

6.3.6 If repositioning the staff plate is not possible and the datum is tied to the original elevation of the staff gage, either discontinue use of the staff gage as the primary gage index and establish a new primary gage index relative to the existing datum, or establish a new datum, adjust related records and document accordingly.

6.4 Determining Stage Height Using a Wire Weight Gage — Wire weight gages are stage height measuring instruments typically attached to a bridge railing or parapet over a stream. The gage is housed in a locked protective covering.

Figure 2 Wire Weight Gage (photo courtesy Rickly Hydrological Company)

6.4.1 The basic parts of a wire weight gage include a drum wrapped with a single layer of cable, and a weight attached to the end of the cable. A readable disc, graduated in tenths and hundredths of a foot is attached to the side of the drum. A Veeder counter, reading in whole feet is also included.

6.4.2 One complete turn of the drum represents one foot of vertical movement of the weight.

6.4.3 The cable is guided to and from the drum by a threading sheave. The weight is held in place at any desired elevation with a pawl and ratchet mechanism.

6.4.4 A moveable check-bar is mounted at the front of the instrument. When the bar is moved to the forward position, the weight rests on it. The check-bar, moved to the forward position, is the reference point for the wire weight gage.

6.4.5 *Operating a wire weight gage* — Open the wire weight gage house. Move the check-bar forward so it rests in position under the weight.

6.4.6 While grasping the drum crank handle, disengage the pawl and lower the weight until it touches but does not fully rest on the check bar.

6.4.7 Read the interval at the pointer on the graduated disc. The numbered hash marks correspond to tenths and five-hundredths of a foot graduations (e.g. 38.45, 32.50, 32.55, etc.). The small hash marks correspond to one-hundredth foot increments (e.g. 38.51). Record the CHECK BAR value on the Stream Gage Logger Notes in the space provided.

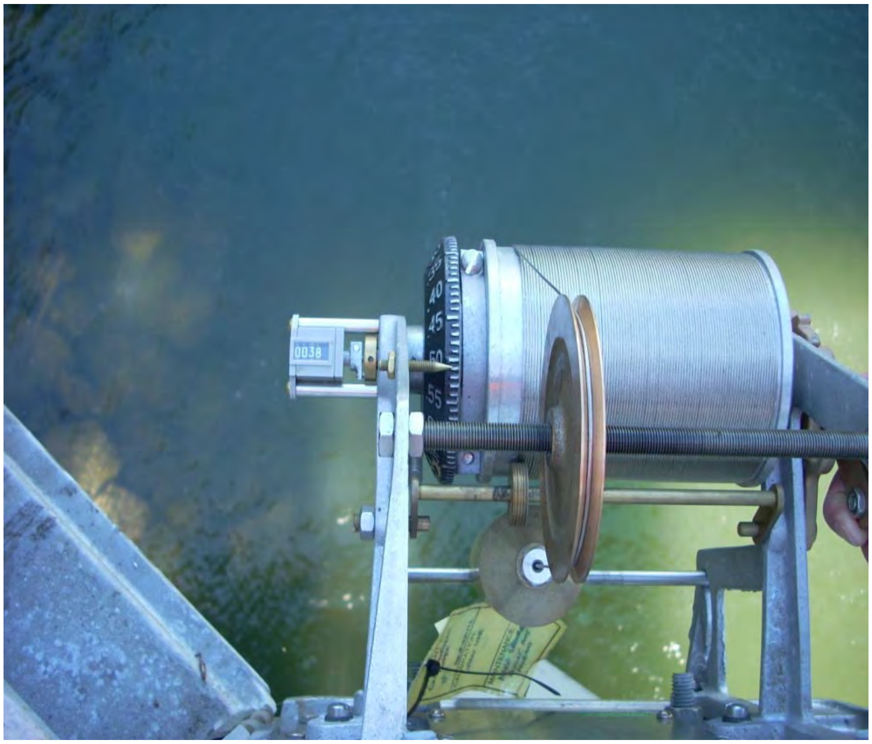


Figure 3 Prior to and after obtaining gage height, lower weight to check bar, and record this value to notes. (Photo by Washington Dept. of Ecology)

6.4.8 The check-bar value as read on the counter and disc should be the same every time the check-bar is read. The station description notes should include the check-bar elevation and the latest date on which levels were run to establish or confirm the elevation.

6.4.9 If the check-bar value does not match, perform the following inspections: Make sure the check-bar is set correctly. Check that the cable is wrapped on the drum properly and the threading sheave is positioned properly, directly above the wrap on the drum. Make sure the graduated disc does not slip (caused by loose clutch screws). Check the Veeder counter for proper operation. Occasionally, the counter is not synchronized with the graduated disc and will not turn over to the next whole foot in synchronization with the disc.

6.4.10 If the check-bar value is satisfactory, slide the bar back and slowly lower the weight to the water surface. The weight should only touch the water surface enough to form a distinctive “V” shape on the water surface.

6.4.11 Read the Veeder counter and disc as previously described. Record the stage height in the WIRE WEIGHT space on the Stream Gage Logger Note form. Wind in the weight. Confirm the check bar elevation and reengage the pawl before closing and locking the wire weight gage enclosure.

6.4.12 The best conditions to read a wire weight gage is when current is moving slowly under the weight and there is no wind. Stage height observations can be difficult in higher velocities when surface waves are present. Attempt to discern the average surface elevation of the peaks and troughs of the waves. Conversely, it is sometimes difficult to determine when the weight touches the water surface if the water is quiescent. Windy conditions cause the cable to bow resulting in under reporting of the water surface (Rantz, et, al., 1975).

6.4.13 Document difficulties encountered in reading a wire weight gage. Quantifying errors in reading wire weight gages is difficult; however noting the potential for error without necessarily quantifying them is still useful in records and measurement evaluations.

6.4.14 Secondary gage indices can be used as a cursory check of the relative accuracy of the wire weight gage. If there is indication the position of the gage has changed, run a set of levels as soon as possible to verify the elevation of the gage.

6.4.15 The datum typically will not change when a wire weight gage is relocated. Using station reference marks the gage can be re-set and adjusted mechanically to calibrate the check bar relative to the established datum.

6.5 <u>Determining Stage Height Using a Laser Level</u>

6.5.1 Laser levels are useful instruments to determine stage height, particularly in areas where staff gages are not practical. The laser level is a portable device mounted on a permanently installed structure or pad of known elevation and emits a laser beam on a level plane.

Figure 4 Laser level mounted on laser level pad. (Photo by Washington Dept. of Ecology)

6.5.2 Stage height is determined by measuring the difference between the known laser beam elevation and the water surface elevation. The elevation of the laser level is confirmed with the use of reference marks placed near the laser level pad.

Figure 5 Reference mark placed near laser level is used to confirm elevation of laser level beam. (Photo by Washington Dept. of Ecology)

6.5.3 *Confirmation of Laser Beam Elevation* — At the time of installation; levels are run to establish the elevation of the laser level pad relative to the station datum.

6.5.4 The laser beam elevation is the elevation of the pad plus the difference between the laser beam plane and the bottom of the laser level instrument mounted on the pad. It is important to distinguish between the elevation of the pad and the laser beam plane. The pad elevation remains the same until the pad is disturbed and the elevation changes. The beam elevation is variable depending on the manufacturer dimensions of the particular laser level model used. All reference mark and water surface elevations are noted and calculated with reference to the beam elevation.

6.5.5 In the immediate vicinity of the laser pad, three reference marks are installed and levels run to establish their respective elevations. The reference marks are placed in locations where a stadia rod is used with the laser level to verify elevations.

6.5.6 The elevations of the reference marks and the last date levels were run to confirm their elevations and are included in the station description.

6.5.7 To confirm the laser beam elevation place the laser level on the pad and power up the instrument. The instrument will self-level if the surface upon which it is placed is level within 5 degrees. If it cannot self-level, the laser light will flash off and on. The pads are installed at or near-level, so unless the pad has been disturbed or the laser level is malfunctioning, the instrument should self-level.

6.5.8 Place the stadia rod on one of the reference marks. Using a circular bubble level as a guide, hold the rod as vertical as possible.

Figure 6 A circular bubble level is used to vertical the stadia rod. (Photo by Washington Dept. of Ecology)

6.5.9 With the laser level powered on and set at level, rotate the device until the laser beam intersects the stadia rod.

6.5.10 Read the rod to the one-hundredth of a foot. The center of the laser light dot projected on the rod is the point at which the stadia rod is read. If the same model of laser level is used for each observation, the rod reading should be the same at each of the three exclusive reference marks.

Figure 7 The center of the laser light dot projected on the rod is the point at which the stadia rod is read. (Photo by Washington Dept. of Ecology)

6.5.11 To check the elevation of the reference marks, compare the rod reading of the laser beam at each reference mark to the established rod reading value for that respective mark. The established rod reading for each reference mark is recorded in the station description notes. Record the established rod reading and the observed rod reading for each laser level reference mark in the appropriate space on the Stream Gage Logger Notes form.

6.5.12 If the laser elevation cannot be confirmed at a given reference mark, check the other reference marks. If the measured elevations of those reference marks match known elevations, it is assumed the unconfirmed reference mark has been disturbed, but the position of the laser level has not changed.

6.5.13 If the rod readings of the other marks do not match, it is assumed the laser has been disturbed and the (previously established) laser elevation is no longer valid.

6.5.14 If the laser elevation is no longer valid, check the differences in elevation between individual reference marks if possible. If these differences remain the same as shown by previous levels, it can be concluded until subsequent levels are run, the reference marks have not moved and only the laser level pad has been disturbed. If this is the case, assign a temporary elevation to a new position of the laser level based on the established elevations of the reference marks. The water surface elevation can be measured based on the new laser beam elevation. Consider this water surface elevation an estimate until levels are run. In most circumstances, the water surface elevation can be checked against secondary gages.

6.5.15 When the laser beam elevation has shifted or reference marks have moved, a set of levels are a high priority and run as soon as possible.

6.5.16 The datum typically will not change when a laser level is relocated. Other reference marks at or near the station are tied to the datum elevation and used to reset the laser level at a datum relative elevation.

6.5.17 *Measuring Water Surface Elevation with Laser Level* — After the laser level beam elevation has been confirmed, measure the water surface elevation.

6.5.18 The stadia rod handler stands the rod vertically on a solid, steady section of substrate in the calmest water practical in the gage pool subject to the station control. Place the rod as close to the primary and recording gage as possible.

Figure 8 The rod is held perpendicular on solid substrate in calm water. (Photo by Washington Dept. of Ecology)

6.5.19 The instrument person rotates the laser level toward the stadia rod until the laser beam is illuminated on the rod. The illuminated point on the rod is read and recorded in the Stream Gage Logger notes under LASER: STADIA ROD READING.

6.5.20 Observe and record the water surface level on the stadia rod in the Stream Logger Gage notes under WATER SFC. ROD READING. Note fluctuations or bounce of the water surface against the stadia rod.

6.5.21 *Calculating Water Surface Elevation* — Subtract the WATER SFC. ROD READING from the LASER: STADIA ROD READING to give the DIFFERENTIAL and enter this value in the space provided on the Stream Gage Logger Notes. The differential is the difference in elevation between the laser beam plane and the water surface.

6.5.22 Subtract the DIFFERENTIAL from the LASER BEAM ELEVATION to give STAGE HEIGHT. Enter this value in the space provided on the Stream Gage Logger Notes.

LASER: STADIA ROD READING	**6.25**				
- WATER SURFACE, ROD READING	**0.34**				
= DIFFERENTIAL, LASER TO WATER SFC	**5.91**				
LASER BEAM ELEVATION	**11.90**				
- DIFFERENTIAL	**5.91**				
= STAGE	**5.99**				

Figure 9 Example of calculation of stage from laser level readings on Stream Gage Logger Note form. (Washington Dept. of Ecology form)

6.6 Determining Stage Height by Tape Down

6.6.1 Measuring stage height by tape down involves lowering a weighted measuring tape to the water surface from a reference point. The reference point is usually a stainless steel washer secured to a bridge railing.

6.6.2 The degree of accuracy and reliability of tape downs in determining stage height is generally inferior to the other methods described in this document. Only use tape downs as a secondary gage.

6.6.3 Fiberglass tapes are light with a wide surface area and prone to errors even in light wind conditions. Fiberglass tapes tend to stretch over time causing biases in tape down measurements. Like the wire weight gage, it can prove difficult to determine stage height when surface waves are present or conversely when water is extremely calm. When waves are present, try to determine the average water surface elevation between the peaks and troughs.

6.6.4 *Measuring Tape Down from Reference Point* — Locate the reference point. Lower the weighted tape to the water surface. The weight should only touch the water surface enough to form a distinctive "V" shape on the water surface.

Figure 10 Tape down weight touching water surface. (Photo by Washington Dept. of Ecology)

6.6.5 Read the tape at the edge of the reference point to one-hundredth of a foot. Enter this value under TAPE DOWN in the space provided in the Stream Gage Logger notes. Note any difficulties reading the tape caused by wind or wave action.

6.6.6 Because the weight is attached to the end of the fiberglass tape, a correction factor is applied to the reference point reading. This correction factor is usually written in permanent marker on the tape housing. Enter this value under CORR. FACTOR in the Stream Gage Logger Notes.

6.6.7 *Calculating Water Surface Elevation* — Add the correction factor to the tape down and enter the sum to CORRECTED TD in both spaces provided in the Stream Gage Logger Notes.

6.6.8 Enter the reference point elevation in the space labeled TD RP ELEVATION on the note form.

6.6.9 Subtract the corrected tape down from the reference point elevation to give the water surface elevation. Enter this value under = WS ELEV@TD on the note form.

TAPE DOWN	**16.32**				
CORR. FACTOR	**0.37**				
CORRECTED TD	**16.69**				
TD RP ELEVATION:	**25.33**				
CORRECTED td	**16.69**				
=WS ELEV@TD	**8.64**				

Figure 11 Example of calculation of stage from tape down readings on Stream Gage Logger Note form.

6.6.10 The datum typically will not change when a tapedown reference point is relocated. Using station reference marks, the reference point can be reset relative to the established datum.

6.6.11 The elevations of the reference mark and the last date levels that were run are included in the station description notes.

6.7 Determining Peak Stage with Crest Stage Gage

6.7.1 The stage measurement equipment and methods previously described are designed to determine stage instantaneously. Crest Stage Gages provide a valuable record of peak stages after the occurrence of high flows. The gage is reliable and relatively simple to install and operate (Rantz, et, al., 1975).

6.7.2 Crest stage gages consist of a 4 foot long, 2 inch diameter galvanized pipe capped on both ends and a wooden staff contained in the pipe. The bottom pipe cap has an arrangement of 6 quarter-inch intake holes. The top cap has a small vent hole. The wooden staff rests on a bolt extending through the bottom of the pipe. The extension of the bolt on the outside of the pipe also serves as a reference point.

6.7.3 The bottom cap contains granulated cork. As water rises in the pipe, the cork floats on the water. When the water reaches its peak and begins to recede the cork sticks to the wooden staff, marking the crest of the high-water event.

6.7.4 At a site visit subsequent to a high flow event, remove the top cap from the crest gage pipe. Carefully pull out the wooden staff. Measure from the bottom of the staff to the high water mark with an engineer’s tape measure.

6.7.5 Clean the cork from the wooden staff to avoid confusion with subsequent high water marks. Rinse residual cork from the inside of the pipe. Replace the granulated cork in the bottom cap. Return the wooden staff into the pipe so that it rests on the bolt. Replace the top cap hand-tight. Be aware of the nail at the top of the staff for flush fit with the cap, and keep the staff vertical in the pipe.

6.7.6 *Calculating Crest Stage* — Record the high water mark in the space HWM _____ FT ON STICK on the back of the Stream Gage Logger Notes form. Record the elevation of the reference point in the space REF ELEV_____ FT adjacent to the high water mark entry.

6.7.7 Add the high water mark and the reference mark elevation and enter the sum under =HWM ELEV_____FT. on the Stream Gage Logger Notes form. This value is the crest stage height.

6.7.8 The datum typically will not change when a crest stage gage is relocated. Using station reference marks, the gage reference point can be reset relative to the established datum.

6.7.9 The elevation of the reference point and the last date levels that were run are included in the station description notes.

7.0 Records Management

7.1 <u>Field Note Forms Archives</u>

7.1.1 All original field note forms including levels notes, stream gage logger notes, and discharge measurement notes are stored in a central locations at Ecology Headquarters, regional, and field offices.

7.1.2 All discharge measurement notes will contain the hand written, original primary gage observations associated with a particular discharge measurement.

7.1.3 Stream gage logger notes contain written stage-height observations of all primary and secondary gages at a site.

7.1.4 Levels notes contain the original notes of gauging site surveys as well as calculations of reference marks and reference point elevations.

7.2 <u>Stage Records in Hydstra Database</u>

7.2.1 All primary and secondary gage observations are recorded and stored electronically to a Hydstra database.

7.2.2 Stage height observations associated with discharge measurements are stored in the Gaugings Database within Hydstra.

7.2.3 A future Standard Operating Procedure document will describe the procedures to enter and store this data to Hydstra data bases.

8.0 Safety

8.1 Personal Flotation Devices are required for persons working in or near streams.

8.2 All EAP safety policies are followed when obtaining stage heights. Refer to the EAP Safety Manual (Environmental Assessment Program, 2015) for further information about working in and around streams.

8.3 Always consider the safety and traffic situations when obtaining gage heights from a bridge and take appropriate actions including suspension of the activity if unsafe conditions exist. Consult the EAP Safety Manual (Environmental Assessment Program, 2015) for further guidance regarding bridge safety.

8.4 When operating laser levels, do not stare into the beam or direct the beam at other persons. Check the path of the beam and ensure there is no danger of inadvertently pointing the beam at people in the vicinity.

9.0 References

9.1 Environmental Assessment Program, 2015. Environmental Assessment Program Safety Manual, March, 2015. Washington State Department of Ecology, Olympia, WA.

9.2 Rantz, S.E., and others. 1975. Measurement and Computation of Streamflow: Volume 1. Measurement of Stage and Discharge. United States Geological Survey Water-Supply Paper 2175.

Attachment A

Washington State Department of Ecology

EAP-FMU Stream Gage Logger Notes

Sta. Name___________________________________

Sta. No. ____________________ **Party** _________________________

DATE					
TIME (PST)					
LOGGER					
STAFF					
WIRE WEIGHT					
CHECK BAR					
TAPE DOWN					
CORR. FACTOR					
CORRECTED TD					
TD RP ELEVATION:					
CORRECTED td					
=WS ELEV@TD					
LASER: STADIA ROD READING					
- WATER SURFACE, ROD READING					
= DIFFERENTIAL, LASER TO WATER SFC					
LASER BEAM ELEVATION					
- DIFFERENTIAL					
= STAGE					
WATER TEMP				ELEVATION	READING
THERMISTER			LL BM1		
AIR TEMP			LL BM2		
THERMISTER			LL BM3		

Batt V __________ Min _________ Max _____________

Reset Stats Y/N Batt replaced Y/N

GOES Time OK Y/N

Data downloaded Y/N .NEW file erased Y/N

Desiccant condition ________________ Changed Y/N

CSG checked Y/N

HWM ________ ft on stick + Ref Elev __________ ft

= HWM Elev _____ ft. Cleaned Y/N

Added cork Y/N

Remarks:

Washington State Department of Ecology

Environmental Assessment Program

Standard Operating Procedure for Measuring and Calculating Stream Discharge

Version 1.2

Author – James R. Shedd
Date – December 8, 2014

Reviewer – Chuck Springer
Date – December 8, 2014

QA Approval - William R. Kammin, Ecology Quality Assurance Officer
Date – December 8, 2014

EAP056

APPROVED: December 8, 2014

Signatures on File

SOP Revision History

Revision Date	Rev number	Summary of changes	Sections	Reviser(s)
10-05-2011	1.1	Revised mean gage height calculation methods in rapidly fluctuation stage conditions.	6.9	J.R. Shedd
		Changed field procedure for assigning quality ratings to discharge measurements.	6.11	
		Updated citations and reference to 2010 edition of EAP Safety Manual.	9.3	
		Removed duplicate paragraph 6.8.3 and renumbered following paragraphs in proper sequence through rest of section.	6.8	
		Added double spacing between paragraphs 6.15.1 and 6.15.2,	6.15	
12-08-2014	1.2	Added method entitled Calculating Discharge When Measurement Location is Considerable Distance from the Gage	6.11	J.R. Shedd
		Added reference to publication cited in section 6.11.	9.5	
		Removed language stating uses of ADCPs are not appropriate in moving bed conditions.	6.3.3.5	
		Removed language referencing out dated QWin discharge calculation program.	6.15.2	
		Added language stating HYGAUGE program calculates discharge using Midsection method.	6.15.2	
		Updated citations and reference to 2012 edition of EAP Safety Manual.	8.0, 9.3	
		Made grammatical and formatting adjustments, rephrased language throughout document.		

1.0 Purpose and Scope

1.1 This standard operating procedure describes the techniques and methods used to measure and calculate stream discharge in a variety of measurement conditions.

2.0 Applicability

2.1 The procedures presented in this document apply primarily to stream discharges measured with mechanical instruments and acoustic velocimeters. However, some sections including but not limited to; Cross Section Selection, Measurement Rating Guidelines, and Assessing the Control also apply to discharges measured with acoustic profilers.

3.0 Definitions

3.1 Midsection Method – A widely used technique for calculating stream discharge, the midsection method involves the calculation of discharge in individual measurement cells in a cross section.

3.2 Cross Section – The measurement cross section is a vertical plane extending from either stream edge, up from the stream bottom to the surface. Depth measurements and velocity samples are taken at about 30 predetermined verticals across the cross section.

3.3 Vertical – A vertical is one of a series of measurement points through the cross section where depth and velocity are measured.

3.4 Primary Gage Index – The primary gage index is the base gage for the station and is directly referenced to the recording gage. The primary gage index is the most stable and reliable gage at a site. All other gages at a station are considered secondary.

3.5 Control – The physical features of a stream that controls the relationship between stage and discharge at a gage site.

3.6 Point of Zero Flow – The point of zero flow is the elevation of the lowest point of a control structure. Flow stops when stage reaches the point of zero flow elevation.

4.0 Personnel Qualifications/Responsibilities

4.1 Personnel using this document will have the training necessary to operate current meters and related equipment. Staff will have knowledge of field and safety procedures associated with the collection of stream flow information.

4.2 Users of this document will typically work in the Environmental Specialist or Hydrogeologist job classifications.

4.3 No special certifications are required.

5.0 Equipment, Reagents, and Supplies

5.1 A standard English four foot, top set wading rod measures vertical depths in streams shallow enough for wading. A velocity meter attached to the top set wading rod measures current speed. The rod is designed to set the current meter at 0.2, 0.6, and 0.8 of the total stream depth.

5.2 The Sontek® FlowTracker® Acoustic Doppler Velocimeter® is used in the majority of wading measurements. The basic components of the FlowTracker® include the under water probe containing the acoustic elements, the probe cable, keypad and controller (Burks, 2009). All of these components attach to a wading rod.

5.3 The primary mechanical current meter used in wading measurement applications is the Swoffer®, Inc. Model 2100® flow meter kit. The flow meter kit consists of a model 2100® digital indicator, sensor cable, and a two inch rotor assembly (Holt, 2009).

5.4 In the case of measurements from a bridge using mechanical equipment, a bridge board or bridge crane is used. Three types of sounding reels are available; USGS Type A and B reels, and a Hydrological Services® Pty Ltd San Winch®. The Swoffer® flow meter kit and the Hydrological Services® OSS-B® current meter are the mechanical instruments used in bridge measurements. The Hydromate® counter registers velocities for the OSS-B1 current meter (Holt, 2009).

Figure 1 Bridge board equipped with a USGS Type A reel. (Photo by Washington Dept. of Ecology)

Figure 2 Bridge crane equipped with a USGS Type B reel. (Photo by Washington Dept. of Ecology)

5.5 Shore operated cableway discharge measurements require the use of a removable sounding reel, permanently installed bearing posts, main tow cable, pulleys, trolley, and related hardware.

5.6 Discharges measured from a boat require specially made equipment. This equipment includes a crosspiece, retractable boom, and a nose piece. A Kevlar® tag line maintains the position of the boat along a cross section.

Figure 3 A boat measurement conducted with necessary equipment attached to a Kevlar® tag line. (Photo by Washington Dept. of Ecology)

5.7 Columbus sounding weights, ranging from 15 to 100 pounds are attached to the cable of the sounding reels in bridge, cableway, and boat measurements.

5.8 Copies of form number 040-56 (Appendix A) for recording discharge notes are stored with a suitable field notebook. These forms are printed on Rite in the Rain™ paper for outdoor durability.

5.9 A fiberglass measuring tape or marked cable is stretched across the measurement cross section or bridge span.

5.10 Good quality hip or chest waders are worn by staff conducting discharge measurements by wading.

5.11 As mandated by the Environmental Assessment Program's Safety Manual (EAP, 2012) an approved personal flotation device must be worn when working in areas where the danger of drowning exists, such as on the water, over the water, or alongside the water.

6.0 Summary of Procedure

6.1 <u>Preparation</u>

6.1.1 Prior to departure complete a Field Work Plan.

6.1.2 Review the equipment checklist (Appendix B) and ensure all field and safety equipment are in the vehicle. Make sure all station information, instructions, and field forms are on hand. Test all stream discharge measuring equipment for proper operation.

6.1.3 Ensure vehicle is equipped to handle the potential driving conditions to and from field destination. Make sure vehicle operates properly before leaving. Check oil level, fluid levels, and tire pressure.

6.2 Measurement Notes

6.2.1 It is important that field staff record clear, detailed notes prior to, during, and after the measurement. Future evaluations of a measurement depend on complete and thorough notes. Record the following information at each discharge measurement:

6.2.1.1 Name of station and station number.

6.2.1.2 Party (person conducting measurement listed first, person recording notes listed second).

6.2.1.3 Note times of gage height observations and logger recordings associated with the measurements in the Gage Readings table on the measurement note sheet. Record all times using 24 hr clock in Pacific Standard Time.

6.2.1.4 In addition note the REW (right edge of water) and LEW (left edge of water). Right and left edges of water are oriented looking downstream.

6.2.1.5 Identify the type of instrument and record the instrument number. If using mechanical equipment, note the propeller or fan number.

6.2.1.6 Record pre and post calibration readings if applicable (Holt, 2009).

6.2.1.7 Record the gage height from the primary and secondary gage indices at the beginning and end of the measurement. Additionally, observe and note the gage height at least once during the course of the measurement to determine if stage is changing.

6.2.1.8 Record the variability in gage height observations, i.e. the range of water level bounce. Record variability in +/- n hundredths of a foot.

6.2.1.9 At stations equipped with continuously recording data loggers, record the time beside the corresponding vertical in the notes every 15 minutes. These time observations are important in determining the mean gage height if stage is changing significantly during the measurement. In the case of stations without a continuous recorder the gage height is manually observed and noted when stage is changing rapidly.

6.2.1.10 Record the water temperature particularly when using acoustic instruments.

6.2.1.11 If measurement statistics are available in electronic form, record width, area, average velocity, and maximum depth. Also include the number of verticals, wetted perimeter and discharge.

6.2.1.12 Record velocity uncertainty, depth uncertainty, and overall uncertainty in the space provided on the note sheet when these statistics are available.

6.2.1.13 Thoroughly describe flow, channel, cross-section, and control conditions. Include descriptions of substrate materials, level of turbulence, areas of slack water and eddies, as well as flow distributions through the cross-section. Note the presence of boulders, logs, and other barriers influencing depth and velocity measurements. Also note ice, vegetation, or debris present in the cross-section or channel. Describe the shape of the channel and note any upstream or downstream structures affecting velocities and flow angles. Refer to section 6.13.6 for direction on documenting control conditions.

6.2.1.14 Describe any situation affecting the accuracy of the measurement or stage and discharge relationship.

6.2.1.15 At the end of the measurement indicate the rating of the measurement in the space provided on the note sheet.

6.2.1.16 Measure and record the point of zero flow if possible.

6.2.1.17 Prior to submittal of notes for review, enter the measurement number, and initials of person compiling notes in the space provided on the note form.

6.2.1.18 The person reviewing the measurement enters their initials in the space provided on the note form.

6.2.1.19 Record vertical locations, depths, and velocities on the back side of the measurement note form. It is important to record velocities in the proper two tenths, six tenths, or eight-tenths column.

6.3 <u>Selecting the Correct Instrument to Conduct a Discharge Measurement</u>

6.3.1 Not all available measurement equipment is designed for use in all measurement situations.

6.3.2 Acoustic Doppler Current Profilers (ADCP) makes an attractive instrument choice because of their convenience and relative ease of deployment. If used appropriately ADCPs provide a more complete and accurate measurement.

6.3.3 However, ADCP's are not designed for use in every measurement situation. The following are circumstances in which an ADCP is not an appropriate instrument choice:

6.3.3.1 Poor depth distribution.

6.3.3.2 High turbulence.

6.3.3.3 Aerated water.

6.3.3.4 Soft or vegetal covered substrate.

6.3.3.5 Debris or fish in the water.

6.3.3.6 Extremely clear water with very little or no turbidity or entrained material.

6.3.4 As a matter of practice, field staff should review the quality of past ADCP measurements at a site. Consider using another type of instrument or changing measurement locations if there were problems with past measurements.

6.3.5 Refer to The Teledyne RD Instruments® (TRDI) StreamPro® Standard Operating Procedure, Version 1.1 (Shedd, et al., 2013) or the WinRiver II Quick Start Guide (TRDI, 2007) for detailed information regarding the proper use of current profilers.

6.3.6 In circumstances where use of an ADCP is inappropriate, use either an acoustic velocimeter or a mechanical instrument.

6.3.7 FlowTracker® velocimeters are preferred over mechanical equipment because of their accuracy, automatic discharge calculation capabilities, statistical presentation of data quality parameters, and lack of moving mechanical parts. The acoustic velocimeter is versatile and can be used in most wading measurement applications. However like the ADCP, the velocimeter will not work in all measurement situations.

6.3.8 Boulders, logs or other large structures collectively referred to as boundaries cause interference with acoustic signals. This interference precludes velocity measurements with velocimeters. Avoid cross sections with significant boundary structures.

6.3.9 Very clear water with very little or no turbidity is another condition in which velocities cannot be measured with these instruments.

6.3.10 Highly turbulent or aerated water can also prohibit the use of the velocimeter.

6.3.11 Mechanical equipment will perform in almost all situations except in velocities less than about 0.10 feet per second. However, the same factors that preclude the use of acoustic instruments may also limit the reliability of mechanical equipment.

6.3.12 If a velocimeter proves unusable because of channel and flow conditions, attempt to find a more favorable measurement location. Use mechanical equipment only when circumstances preclude the use of acoustic equipment.

6.4 Selecting a Cross Section

6.4.1 Before conducting a stream discharge measurement field staff make considerable efforts to locate the best available measurement cross section. If the stream cannot be waded and an Acoustic Doppler Current Profiler (ADCP) is not practical, conduct the measurement from a bridge, cableway, or boat.

6.4.2 In the case of ADCP and wading measurements the selection of a suitable cross section cannot be over emphasized. The quality of equipment or the ability of the individuals conducting the measurement cannot overcome the limitations in measurement quality caused by a poor cross section. The choice of cross sections is obviously limited when measuring from a bridge, cableway, or boat.

6.4.3 Field staff look for the following characteristics in an ideal measurement cross section (Rantz, 1982):

6.4.3.1 A stream channel relatively straight with parallel edges upstream and downstream of the cross section.

6.4.3.2 Defined edges on both sides of the cross section.

6.4.3.3 A channel of uniform shape.

6.4.3.4 A channel free of vegetative growth, large cobbles, and boulders.

6.4.3.5 A cross section free of eddies, slack water, and turbulence.

6.4.3.6 A cross section with depths greater than 0.5 feet.

6.4.3.7 Velocities greater than 0.5 feet per second and distributed evenly through the cross section.

6.4.3.8 A cross section relatively close to the gaging station control to avoid the inflow of tributaries and differences in relative flow between the control and cross section during periods of changing stage.

6.4.4 Meeting all of the selection criteria is often not possible. Field staff should choose the best available cross section based on these characteristics.

6.5 Dividing the Stream Channel into Segments

6.5.1 After locating a satisfactory cross-section, stretch a measuring tape or marked tag line across the measurement cross section. The tape or tag line extends across the channel perpendicular or normal to the direction of flow. Limit the number of cells with oblique flow angles, i.e. cells with current angles not perpendicular to the cross section.

6.5.2 Note the width of the stream channel at the cross section and divide into measurable segments or cells. Divide the cross-section such that approximately five percent and no more than ten percent of the total flow is within any one segment. In most cases divide the cross section into approximately 30 segments. Position verticals closer together where flow is more concentrated and velocity variation or bottom irregularities are greatest.

6.5.3 The width of a measurement segment should not be less than three tenths of a foot.

6.6 <u>Measuring Velocity</u>

6.6.1 Measure velocity at each pre-determined vertical across the stream. Although velocity is evenly distributed in ideal cross sections, there can be significant variability in stream velocity throughout a less than ideal cross section. Velocity varies horizontally across the cross section and vertically through the water column. Velocity also naturally pulses in streams at any single location over short periods of time.

6.6.2 *Horizontal Velocity Variation*

6.6.2.1 Channel geometry, substrate, and other stream features cause horizontal variability between stream segments. Field staff can minimize measurement uncertainty due to horizontal velocity variation by applying these guidelines:

6.6.2.1.1 Divide the stream cross-section into about 30 segments. If previous measurements show uniformity of the cross section and an even velocity distribution, fewer verticals are permissible (Rantz, 1982).

6.6.2.1.2 Concentrate the distribution of segments where discharge is highest and in areas where significant velocity variation occurs.

6.6.2.1.3 Increase the number of verticals in vicinity of bridge piers.

6.6.3 *Vertical Velocity Variation*

6.6.3.1 In most natural stream conditions, a logarithmic relationship exists between velocities through the water column. Typically velocities are highest in the upper portion of the water column and lower near the bottom. Address vertical velocity variability within a segment using one of the following methods, depending on measurement conditions.

6.6.3.1.1 Six tenths method: Sample velocities at sixth tenths of the depth from the water surface. Assume velocity samples at six tenths of depth represent the average velocity through the water column. Use the six tenths method at stream segments less than 1.5 feet in depth. Use the six tenths method at all depths when stage is fluctuating rapidly.

6.6.3.1.2 Two point method: Employ the two point method at verticals where depths are greater than or equal to 1.5 feet. Velocities are sampled at two tenths and eight tenths of the depth, and the results are averaged.

6.6.3.1.2.1 When measuring from a bridge, cableway, or boat, use the two point method at depths greater than or equal to 2.5 feet.

6.6.3.1.3 Three point method: The three point method consists of velocity samples at two tenths, six tenths, and eight tenths of depth. Use the three point method when a logarithmic relationship does not exist between strata of velocities through the water column.

6.6.3.1.3.1 Presume a non logarithmic relationship exists when the two tenths velocity is less than the eight tenths velocity or the two tenths velocity is greater than two times the eight tenths velocity.

6.6.3.1.3.2 To calculate the average velocity for the vertical, average the six tenths velocity sample against the mean of the eight tenths and two tenths velocity samples, thus weighting the six tenths sample as half of the calculated velocity for the vertical.

6.6.4 *Single-Point Velocity Variation*

6.6.4.1 Stream velocities in natural conditions tend to pulse over time at the same stage. These fluctuations compound the effects of horizontal and vertical velocity variability at fixed locations in the stream. Apply the following guidelines to address single point velocity variability:

6.6.4.1.1 Take 40 second velocity samples to address variations in velocity over time at a single measurement point.

6.6.4.1.2 Measure 40 second velocity samples at each measurement point except when stage is rapidly fluctuating, or when velocities less than 0.5 feet per second exist when measuring with mechanical instruments.

6.6.4.1.3 In circumstances when stage fluctuates significantly, take single 20 second velocity samples to complete the discharge measurement quickly.

6.6.4.1.4 When using mechanical equipment, increase the sample time to 60 seconds when velocity is less than 0.5 feet per second.

6.7 Adjusting Velocities of Oblique Flow Angles

6.7.1 Pay close attention to the direction of flow when using mechanical current meters. The velocity of the current normal or perpendicular to the cross section must be determined to calculate discharge correctly.

6.7.2 The following procedure does not apply to SonTek® velocimeters as they are always pointed perpendicular to the cross section. SonTek® velocimeters automatically calculate and report velocity as normal to the cross section (Burks, 2009).

6.7.3 Ecology's Freshwater Monitoring Unit's mechanical instruments consist of horizontal axis type current meters. In wading measurements mechanical meters should be pointed into the current when the angle of the current, relative to the perpendicular of the cross section is greater than 15 degrees. When the meter is suspended by a cable the meter will automatically point into the current.

6.7.4 At any measurement vertical, when a mechanical meter is pointed into an oblique current greater than 15 degrees from the perpendicular of the cross section, multiply the registered velocity by the cosine of the angle. This calculation yields velocity normal to the cross section. An approximate 3.5 percent difference exists between registered velocity at a 15 degree current angle and the calculated velocity normal to the cross section. A 20 degree angle results in a greater than 6 percent difference between registered and calculated velocity normal to the cross section.

6.7.5 Determine the cosine in the field with the use of the Ecology Discharge Measurement Note sheet number 040-56 (Appendix A).

6.7.5.1 On the back side of the form locate the dot in the center of the left margin. Cosine values are on the right side of the page as well as the top and bottom. Hold the note sheet horizontally with the dot over the measuring tape if wading, or the edge of a bridge rail if conducting a bridge measurement. Position the note sheet such that the long edge of the sheet is parallel to the direction of the current. The measuring tape or bridge rail edge will intersect the cosine value on the right edge, top, or bottom of the sheet. Multiply the cosine value by the registered velocity to obtain the velocity normal to the cross section.

6.7.5.2 In many instances when measuring discharge from a bridge, the entire stream channel is at an oblique angle to the cross section defined by the bridge. In this case multiply the raw average velocity of the measurement by the cosine of the angle between current direction and the cross section.

6.8 Measuring Discharge When Stage Is Fluctuating Rapidly

6.8.1 Field staff should streamline measurement methods to obtain a more representative gage height when stage changes rapidly. Some accuracy in the measurement is sacrificed. However the error caused by changing flow patterns in rapidly changing stage situations is greater than the loss of accuracy in a streamlined discharge measurement (Buchanan and Somers, 1969).

6.8.2 Generally, rapidly changing stage occurs when stage fluctuates at a rate greater than 0.1 feet per hour. Be aware that measurements conducted during or after storm events, impoundment or diversion activities, or seasonal snow melt periods are the most likely times to encounter rapidly changing stage conditions. When stage is fluctuating rapidly:

6.8.2.1 Measure velocities using the six-tenths method regardless of depth.

6.8.2.2 If the six tenths method is not possible, use either the two tenths, subsurface, or surface methods presented in section 6.10.

6.8.2.3 Reduce velocity sampling time to 20 seconds.

6.8.2.4 Reduce the number of verticals to 15 or 20.

6.8.2.5 At sites with continuous stage height recorders, record the time every 15 minutes on the note sheet corresponding to the vertical measured at that time.

6.8.2.6 In the case of non-recoding stations, manually read and note gage heights. Observation times are recorded on the note sheet next to the corresponding vertical.

6.8.2.7 This record of stage and corresponding observation times are used in the calculation of a weighted mean gage height.

6.9 <u>Calculating Mean Gage Height When Stage Is Fluctuating Rapidly</u>

6.9.1 The mean gage height of a discharge measurement and the discharge value itself comprise the two plotted coordinates used to establish a rating. An accurate determination of mean gage height is as important as the accuracy of a discharge measurement.

6.9.2 At continuously recording stations the stage record during the time of the measurement is checked against the recorded times on the measurement sheet. Check the record for the amount of fluctuation in stage during the measurement.

6.9.3 If changes in stage occurred during the measurement and the changes are uniform and less than about 0.1 feet, mean gage height is determined by calculating the average of the beginning and ending gage height readings (Buchanan and Somers, 1969). Use judgment in determining the allowable change in gage height where a simple mean gage height is calculated. Consider the percentage of discharge the change in stage represents at smaller streams.

6.9.4 If the change in stage is greater than 0.1 feet or the change is not uniform a weighted mean gage height for the measurement is calculated. Two methods are used to obtain a weighted mean gage height. The first, called Partial Discharge Weighting is only appropriate for use with discharges measured with mechanical equipment or acoustic velocimeters. The second method, Time Weighting, is used with all measurement equipment including Acoustic Doppler Current Profilers. When mechanical equipment or acoustic velocimeters are used both methods are employed and the separate results averaged to obtain a weighted mean gage height.

6.9.4.1 With the Partial Discharge Weighting method, the discharge between recorded times during the measurement, the mean gage height for the corresponding time periods, and the total measured discharge are used to compute a mean gage height. The Partial Discharge Weighting formula is

$$H = \frac{\mathrm{q_1 h_1 + q_2 h_2 + q_3 h_3 \ldots . + q_n h_n}}{\mathrm{Q}}$$

where
H = mean gage height
Q = total discharge = $q_1 + q_2 + q_3 \ldots . + q_n$
where $q_1 + q_2 + q_3 \ldots . + q_n$ = discharge measured during time interval 1, 2, 3, ….*n* and
$h_1 + h_2 + h_3 \ldots . + h_n$ = average gage height during time interval 1, 2, 3,….n.

6.9.4.1.1 In figure 4 an example of a partial discharge weighting calculation is presented. The gage height is recorded every 15 minutes from 13:30 to 14:30. The average gage height (h) is calculated between each 15 minute interval. The sum of the discharges of each cell (q) measured in the 15 minute interval is computed. Each of these discharges are summed to give Q = 76.37. The product h*q is calculated and the products summed to give Sum(h*q) = 135.43. To calculate the mean gage height H, divide Sum(h*q) by Q in the form $\frac{135.43}{76.37}$ to give a mean gage height of 1.77 feet.

Example:

Time	Gage Height	h	q	h*q
13:30	1.94			
		1.92	***16.1***	**30.91**
13:45	1.90			
		1.70	***24.31***	**41.33**
14:00	1.49			
		1.67	***20.99***	**35.05**
14:15	1.85			
		1.88	***14.97***	**28.14**
14:30	1.92			

Q = 76.37 **Sum(h*q) = 135.43**

$$H = \frac{135.43}{76.37} = 1.77\ feet$$

Figure 4 Example of partial discharge weighting calculation method.

6.9.4.2 The Time Weighting method uses the mean gage heights between the noted times, the duration of those times, and the total time of the measurement. The Time Weighting formula is

$$H = \frac{\mathrm{t_1h_1 + t_2h_2 + t_3h_3 \ldots. + t_nh_n}}{T}$$

where
H = mean gage height
T = total time for the measurement, in minutes = $t_1 + t_2 + t_3 \ldots. t_n$,
$t_1,\ t_2,\ t_3 \ldots. t_n$ = duration of time intervals between gage height observations, and
$h_1, h_2, h_3 \ldots. h_n$ = average gage height during time interval 1, 2, 3, ….n.

6.9.4.2.1 In the example below the average gage heights (h) from the discharge weighting example are used. The product of each time interval between gage height readings (t) and (h) are calculated to give h * t. The four 15 minute time intervals in the example are added to give a total time of 60 minutes. The products of h * t are summed to give a total of 107.55. The summed products of h * t are divided by the total time in the form $\frac{107.55}{60}$ to give a mean gage height of 1.79 feet.

Example:

h	Time interval (t)	h * t
1.92	15	28.80
1.70	15	25.50
1.67	15	25.05
1.88	15	28.20
Total	60	107.55

$$H = \frac{107.55}{60} = 1.79\ feet$$

Figure 5 Example of time weighted calculation method.

6.9.5 Studies by the United States Geological Survey indicate the Partial Discharge method tends to overestimate the mean gage height and the Time Weighted method underestimates the mean gage height. For that reason it is recommended that both methods are computed and the two results averaged (Rantz, 1982). Keep in mind both methods are only applied to measurements where mechanical instruments or acoustic velocimeters were used. In the above examples the mean stage for the measurement using the results of both methods is 1.78 feet.

6.10 Measurement and Calculation Techniques When High Velocities Preclude Depth Soundings or Conventional Velocity Observations

6.10.1 If velocity is too great to make depth soundings or obtain conventional velocity samples, three alternative methods make discharge estimations possible. These are the two tenths method, the subsurface velocity method, and the surface velocity method.

6.10.2 *Two Tenths Velocity Method*

6.10.2.1 Calculation of velocity using the two tenths depth method involves sampling velocity at 0.2 of the depth from the surface and applying a coefficient derived from the point to mean velocity ratio. The point to mean velocity ratio refers to the calculated or estimated ratio between the measured velocity at two tenths depth, and the mean velocity of the entire water column.

6.10.2.2 In circumstances where depths can be reliably sounded but velocity cannot be sampled at 0.6 or 0.8 of depth because of drift debris or other reasons, sample velocity at 0.2 of the measured depth.

6.10.2.3 In situations where soundings are not possible, depths can be estimated when a reliable standard cross section or some knowledge of the bottom contour is available (Buchanan, Somers, 1969).

6.10.2.4 Coefficients applied to two tenths depth velocities are most reliable when derived from velocity curves from the specific location as opposed to published velocity curves. Develop a velocity curve between two tenths velocities and true mean velocities by recalculating past measurements. Recalculate complete measurements or measurement segments where 0.8 and 0.2 depth velocity samples were measured, using only the 0.2 velocity in the calculation. By plotting the true mean velocities versus the two tenths velocities for each measurement a mathematical relationship can be derived.

6.10.2.5 Studies conducted by USGS indicate that for a given cross section the relationship between the two tenths and true mean velocities remains constant or varies uniformly with stage (Rantz, 1982).

6.10.2.6 USGS Water Supply Paper 2175 (Rantz, 1982) provides a vertical velocity graph and table of point to mean velocity ratios. This graph and table were developed through intensive study of vertical velocity curves. If an insufficient number of measurements have been conducted to derive a reliable relationship at a specific site, the replicated graph (figure 6) and table 1 may be used to calculate point velocities. The point velocity is derived from the table by dividing the measured velocity by the ratio of point velocity to mean velocity. For example the ratio applied to a velocity measured at 0.2 of depth is calculated in the form $\frac{V}{1.149}$

where v is the measured velocity and the denominator of 1.149 is the ratio of point velocity to mean velocity at 0.2 of depth found on table 1.

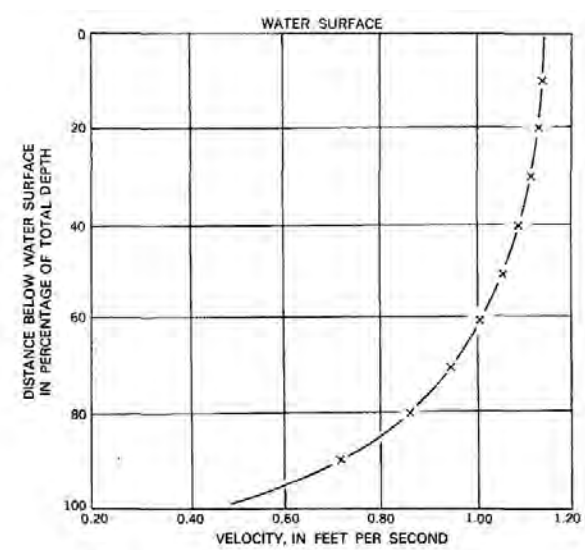


Figure 6 Graphical representation of standard vertical velocity curve developed by USGS. (Illustration from USGS Water Supply Paper 2175, pg. 133.)

Table 1 Point to mean velocity ratios for standard vertical velocity curve.
(Table from USGS Water Supply Paper 2175, pg. 133.)

Ratio of observation depth to depth of water	Ratio of point velocity to mean velocity in the vertical
0.05	1.160
.1	1.160
.2	1.149
.3	1.130
.4	1.108
.5	1.067
.6	1.020
.7	.953
.8	.871
.9	.746
.95	.648

6.10.3 *Subsurface Velocity Method*

6.10.3.1 Use the subsurface velocity method if measuring or estimating depth is not possible or practical.

6.10.3.2 Sample velocities at an arbitrary depth at least two feet below the surface.

6.10.3.3 Determine depths by soundings made at a later measurement when the flow has receded. Calculate the difference between the gage heights of the two measurements to estimate depths and meter elevations at the time of the subsurface velocity measurement. Compare cross sections of previous measurements with the cross section of the latest measurement to determine if the cross section has shifted (Buchanan, Somers, 1969).

6.10.3.4 With the known depths of the current meter, the ratio of point of velocity observation to vertical depth is computed.

6.10.3.5 As previously described, point velocity to mean velocity ratios can be obtained from velocity curves developed for the specific site. Use the graph in figure 6 and table 1 if a velocity curve specific to the site is not available.

6.10.3.6 A simple example of this application follows: Based on soundings subsequent to a subsurface velocity sample at a certain vertical, the depth at the time of the sample is calculated at 10 feet. Velocities were sampled at 3 feet below the surface. The ratio of point of velocity observation to vertical depth is $\frac{3feet}{10feet} = 0.3$. Table 1 shows the ratio of point velocity to mean velocity in the vertical at 0.3 of depth is 1.13. Calculate the adjusted velocity at 0.3 of depth in the form $\frac{V}{1.13}$ where v is the measured velocity and the denominator 1.13 is the ratio of point velocity to mean velocity.

6.10.4 *Surface Velocity Method*

6.10.4.1 If obtaining velocities below the surface is not practical or possible, the surface velocity method may be used. Lower the meter to just below the water surface to sample the velocity. The coefficient used to calculate mean velocity is 0.85, or divide the sampled velocity by 1.18 (Rantz, 1982).

6.11 <u>Calculating Discharge When Measurement Location is Considerable Distance from the Gage</u>

6.11.1 In some instances significant distance separates the measurement location from the gage. When water surface elevations in a long stream reach with no tributaries are steady, discharge along the reach remains near constant. However as water surface elevations change, discharges can vary greatly along the reach due to channel storage effects. Channel storage effects occur as water surface elevations rise or fall in a reach. As the water surface elevation rises some water goes into storage. As water surface elevation falls water comes out of storage. Discharge is greater at the inflow than the outflow of a reach as water goes into storage. Conversely discharge is greater at the outflow than the inflow when water comes out of storage. The degree of channel storage effect in a given reach depends on channel shape, sinuosity, roughness, slope, influences of control structures among other factors. Figure 7 shows a hypothetical stream reach illustrating channel storage effects.

6.11.2 When changes in water surface elevation occur between the gage and measurement locations, the differences in discharge must be determined. The objective in accounting for these differences is to determine the discharge at the gage at the time of the measurement.

6.11.3 Use the channel storage calculation method presented below, anytime the possibility exists of a difference in flow between the measurement location and gage. Keep in mind the channel storage calculation cannot account for inputs of tributaries, losses to diversions, gains from irrigation returns, as well as gains and losses from groundwater interactions within the reach.

6.11.4 The rate of change in the water surface elevation and average water surface area in the reach defines the relationship between the inflow and outflow and is the basis for the channel storage equation (Kennedy, 1984).

6.11.5 The channel storage equation is

$$Qi - Qo = \frac{L \text{ x } W \text{ x } J}{3{,}600}$$

where
Qi is inflow in cubic feet per second,
Qo is outflow in cubic feet per second,

L is the length of the reach in feet,
W is the average width of the reach in feet, and
J is the average rate of change of the water surface elevation through the reach in feet per hour (expressed as positive for a rising water surface elevation, negative for falling water surface elevation). The value of J computes as follows:

$$J = (60/t)\ \frac{\pm Si + \pm So}{2}$$

where
t is the elapsed time of the measurement in minutes,
Si is change in stage at inflow, and
So is change in stage at outflow.

Since J is the rate of change in feet per hour. The use of the devisor 3,600 (the number of seconds comprising one hour) in the channel storage equation expresses Q in cubic feet per second.

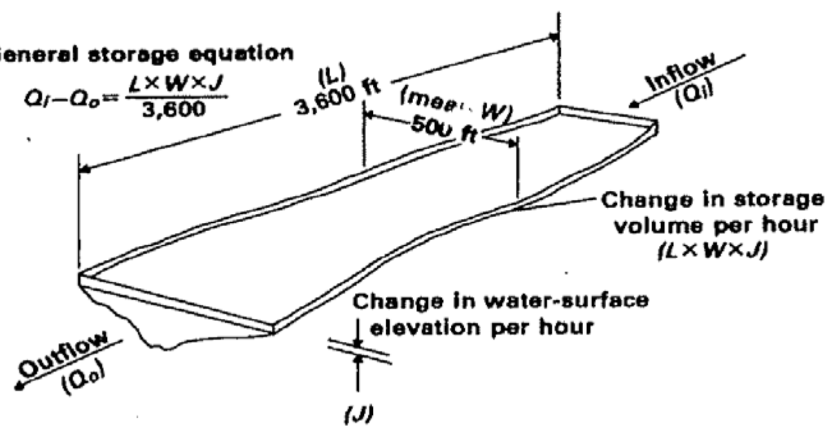


Figure 7 Hypothetical stream reach illustrating channel storage effects. (Illustration from USGS Publication, Discharge Ratings At Gaging Stations, pg. 3.)

6.11.6 Using the stream reach dimensions in figure 7, suppose a gage is established at the outflow of the reach and the measurement cross-section located upstream at the inflow. Further suppose the measured discharge at the inflow was 1,000 cfs and the water surface fell 0.6 feet at the measurement site and 0.4 feet at the downstream gage for an average change in water surface elevation through the reach of -0.50 feet. The hypothetical measurement took one hour to complete. Again, the objective is to determine the discharge at the gage.

6.11.7 Applying the channel storage equation to the dimensions of the hypothetical stream reach, with the provided measured discharge and water surface change information, compute the outflow discharge as

$$1{,}000 - Qo = \frac{3{,}600 \text{ x } 500 \text{ x } \left(\left(\frac{60}{60}\right) \text{ x } \left(\frac{(-.6) + (-.4)}{2}\right)\right)}{3{,}600}$$

The calculated outflow discharge (Qo) at the gage = 1,250 cfs. This is an example of water coming out of channel storage because the calculated outflow is greater than the measured inflow.

6.11.8 At the same hypothetical stream reach suppose the gage this time is located at the inflow and 2,000 cfs was measured downstream at the outflow. The average change in water surface elevation was 0.30 and the measurement took 45 minutes to complete. The inflow discharge at the gage is computed as

$$Qi - 2{,}000 = \frac{3{,}600 \text{ x } 500 \text{ x } \left(\left(\frac{60}{45}\right) \text{ x } 0.30\right)}{3{,}600}$$

In this example the calculated inflow discharge (Qi) at the gage = 2,200 cfs. Here water is going into channel storage because the inflow is greater than the outflow.

6.11.9 In order to calculate as accurately as possible a discharge corresponding to the gage location, acquire the best possible measurements of reach length and average width. If practical physically measure reach dimensions; otherwise use quadrangle maps, orthophotos, the StreamStats program or other sources to determine reach width and length. Do not simply guess the dimensions of a reach.

6.11.10 Prior to conducting a measurement at a distant location from the gage, set an appropriate reference mark at the measurement location to determine change in water surface elevation over the course of the measurement. Changes in water surface elevations at the gage are determined by gage height observations or logger recordings before and after the measurement.

6.11.11 Enter the adjusted discharge value to the measurement record in the Gaugings Database in the Hydstra program. Assign the appropriate quality code to the calculated measurement value keeping in mind the variables and potential uncertainty involved in determining discharge based on a measurement conducted at a distant location from the gage.

6.12 Rating a Measurement

6.12.1 At the conclusion of each measurement, field staff apply a rating of the measurement on a scale from excellent to poor. This field rating forms the basis of the final quality code assigned to the measurement by the station's principle investigator.

6.12.2 Field staff base the measurement rating on observed conditions as well as quality analysis statistics available in the field. Acoustic velocimeters' and current profilers' operating systems offer comprehensive analytical packages.

6.12.3 The desirable characteristics of a measurement location serves as the basis for rating the physical conditions of the channel and cross section. Field staff observe the degree in which each of these characteristics influence the quality of the measurement.

6.12.4 Take into account factors such as the proximity of bridges and other structures to the cross section. These structures can effect velocity distribution and uniformity of depth (Rantz, 1982).

6.12.5 Consider the number of corrected velocities because of oblique current angles. Keep in mind the assumption that the angle observed at the surface prevails through the entire vertical may be incorrect. Numerous angles of flow approaching the cross section from various directions may indicate turbulence resulting in non representative velocity samples.

6.12.6 Take notice of the condition of the equipment. Rate the measurement accordingly if problems with equipment occurred during the measurement.

6.12.7 Look at the role of the weather in the measurement. Wind over the water surface can obscure the direction of flow. Cold weather may cause ice or slush to form in the cross section. Ice or slush can adversely affect the operation of mechanical current meters and the ability to measure depth accurately.

6.12.8 Water level bounce and velocity pile up on wading rods and stadia rods adds uncertainty to depth determinations. Take into account these factors when rating a measurement.

6.12.9 Not all of the variables affecting the quality of a discharge measurement are described here. Field staff must consider all the conditions and use professional judgment in rating a measurement.

6.12.10 The principle investigator or basin lead thoroughly reviews all of the components of the field rating and renders the final decision in all quality code assignments. It is extremely important field notes are thorough and complete.

6.12.11 Rate measurements as excellent, good, fair, or poor on the discharge note form. An excellent measurement indicates the measured discharge value is within 2 percent of the actual flow value. A rating of good means the measured value is within 5 percent. A fair rating of a measurement indicates the measured value is within 8 percent. Poor means the error in the measured flow is within 13 percent of the actual discharge.

6.12.12 Field staff do not consider the level of difficulty in obtaining gage height observations in the measurement rating. Base the rating solely on measurement conditions. However, field staff should focus particular attention in field notes on the circumstances and degree of difficulty in obtaining an accurate gage height observation. Consider water level bounce and velocity pile up on staff gages or stadia rods. Wind can cause wave action that may make it difficult to locate the water surface with sounding weights. The principle investigator considers carefully these factors in formulating the final rating.

6.12.13 In addition when stage changes rapidly, some accuracy is lost when purposefully accelerating the measurement. Stage determinations in these circumstances are often calculated rather than directly observed. Rate the measurement appropriately in these circumstances.

6.13 Assessing the Control

6.13.1 The physical features of a stream that regulates the relationship between stage and discharge at a gage site is the control.

6.13.2 There are three basic types of controls; section control, channel control, and flood plain control. The following discussion focuses on section and channel controls.

6.13. 3 *Section Control*

6.13.3.1 A section control governs the stage and discharge relationship in a localized reach of the stream, downstream from the gage. The section control can be a natural or artificial structure, a channel constriction, or a downward break in slope in the stream bed.

6.13.3.2 Common section control structures include the buildup of rocks and boulders, or woody debris stretched across the channel. Manmade dams, weirs, or water diversion structures often serve as section controls. Channel constrictions can include rock outcrops or gravel bars. Bridges where the waterway opening is narrower than the natural channel is a common section control caused by channel constriction. Downward breaks in the slope of a streambed include heads of riffles, cascades or the brink of a falls.

Figure 7 This section control is defined by the downward break in slope at the head of the riffle.   (Photo by Washington Dept. of Ecology)

6.13.3.3 At some stations more than one section control may be present. In these instances an upstream section control is in effect at lower stages. At higher stages another downstream section control becomes effective.

6.13.4 *Channel Control*

6.13.4.1 Channel control exists when the physical attributes of a long reach of the channel controls the relationship between stage and discharge. These physical attributes include shape, length, width, slope, sinuosity, and roughness of the channel. The length of the channel as an effective control increases as discharge increases (Rantz, 1982).

Figure 8 An example of channel control at the same location as figure 7. (Photo by Washington Dept. of Ecology)

6.13.5 *Control Dynamics*

6.13.5.1 Typically, section control is effective at lower stages and channel control effective at higher stages. An intermediate range of flows are subject to partial control. Partial control occurs when the relationship between stage and discharge is governed by both section and channel controls or by two separate section controls. As flows increase, section control is progressively drowned out by channel control. Partial control occurs between two section controls when stage increases such that the downstream control becomes increasingly effective.

6.13.5.2 The propensity of the channel to change over time determines the stability of the station controls. If high flow events frequently cause scour or filling of a channel, the controls are unstable. If a control changes frequently, the stage and discharge relation changes frequently. If controls are stable, the stage and discharge relationship remains stable.

6.13.5.3 Ideally all stations would have stable controls. Unfortunately this is not the case in the natural environment. Stations with unstable controls require frequent adjustment of rating curves. Additional measurements are required to establish new ratings rather than further define and reaffirm existing ones. More time is needed to manage records when ratings need frequent adjustment. This increases the costs to operate a station and can reduce the timeliness, and reliability of discharge records.

6.13.6 *Documenting the Condition of Controls*

6.13.6.1 Because controls may change over time, field staff must monitor and document the condition of controls at each discharge measurement. The station's principle investigator will need detailed information about the control if a change in rating occurs.

6.13.6.2 Field staff should identify the effective control or if there is a partial control situation. If section control is in effect, note the location of the control relative to the gage. Note the type of section control i.e., the control is a structure in the stream, or the control constricts flow like a gravel bar or outcrop. Note the materials making up the section control. Have copies of past notes or photos on hand to document changes in the control relative to previous visits.

6.13.6.3 It is important to note any forms of seasonal vegetal growth or ice on or around the control, and on the bed and banks. Aquatic vegetation and ice on the control or in the channel alters the stage and discharge relationship by reducing velocity and the effective waterway area (Rantz, 1982).

6.13.6.4 In autumn the accumulation of leaves can temporarily change the stage and discharge relationship. Note the extent of accumulation of leaves on the control or in the channel where the stage and discharge relation may be impacted.

6.14 Measuring the Point of Zero Flow

6.14.1 The point of zero flow (PZF) is the lowest point on a control and the stage at which flow ceases.

6.14.2 Identify and measure a PZF whenever possible. A determination of the PZF is important because it helps define the lower end of a rating and serves as a first estimate of the off-set of a rating.

6.14.3 A change in PZF elevation or location indicates alteration of the control. A measurable alteration in the control can signify a shift in the rating.

6.14.4 Attempt to measure a PZF only when it is safe to do so. Follow these steps to identify and determine a PZF:

6.14.4.1 Locate the section control.

6.14.4.2 Take depth soundings across the control with a wading rod.

6.14.4.3 Locate and measure the depth of the PZF, the deepest point of the control.

6.14.4.4 Include in the depth reading the pile up of water on the wading rod.

6.14.4.5 Note the depth of the PZF to the nearest one-tenth of a foot.

6.14.4.6 Note the locations of the control and the PZF.

6.14.4.7 Take photographs of the control.

6.14.4.8 Calculate PZF by subtracting the depth of the PZF from the gage height. Record PZF on the bottom of Form 040-56 (Appendix A).

6.14.5 Keep a record of PZF soundings and locations in station notes.

6.15 Calculating Stream Flow Using the Midsection Method

6.15.1 Ecology's Freshwater Monitoring Unit uses the midsection method to calculate stream flows measured with mechanical current meters or acoustic velocimeters.

6.15.2 The equations comprising the midsection method are written into a variety of computer programs. The SonTek® FlowTracker® contains a built in midsection calculation program to calculate discharge (Burks, 2009). In addition the Hydstra

Gaugings Calculator Program HYGAUGE uses the midsection method to calculate measured discharges conducted with mechanical instruments.

6.15.3 Although computation of discharge by hand is virtually unnecessary, an understanding of the midsection calculation method can influence strategies and decisions while conducting discharge measurements.

6.15.4 The midsection calculation method involves summing the discharges of the individual cells comprising the cross section. This is expressed in the following equation, $Q = \sum(a\,v)$ where
Q = total measured discharge
a = area of individual cell
v = mean velocity of individual cell, normal to the cross-section.

6.15.5 The discharge of an individual cell is the product of its area and mean velocity normal to the cross section.

6.15.6 The area of the cell extends laterally half the distance from the previous vertical to half the distance to the next. The area also extends vertically from the water surface to the sounded depth. Evenly spaced verticals are not necessary. The mean velocity sampled at the vertical represents the velocity through the entire cell.

6.15.7 The discharge of any cell at vertical x is represented in the equation,

$$q_x = v_x \left[\frac{\left(b_x - b_{(x-1)}\right)}{2} + \frac{\left(b_{(x+1)} - b_x\right)}{2}\right] d_x$$

$$= v_x \left[\frac{b_{(x+1)} - b_{(x-1)}}{2}\right] d_x$$

where
q_x = discharge through cell x,
v_x = mean velocity at vertical x,
b_x = distance from initial point to vertical x,
$b_{(x-1)}$ = distance from initial point to preceding vertical,

$b_{(x+1)}$ = distance from initial point to next vertical, and
d_x = depth of water at vertical x.

6.15.8 For example, the discharge in highlighted cell 4 in figure 9 is expressed as $q_4 = v_4 \left[\frac{b_5 - b_3}{2}\right] d_4$.

6.15.9 The total discharge of the stream is equal to the sum of the discharges of each cell.

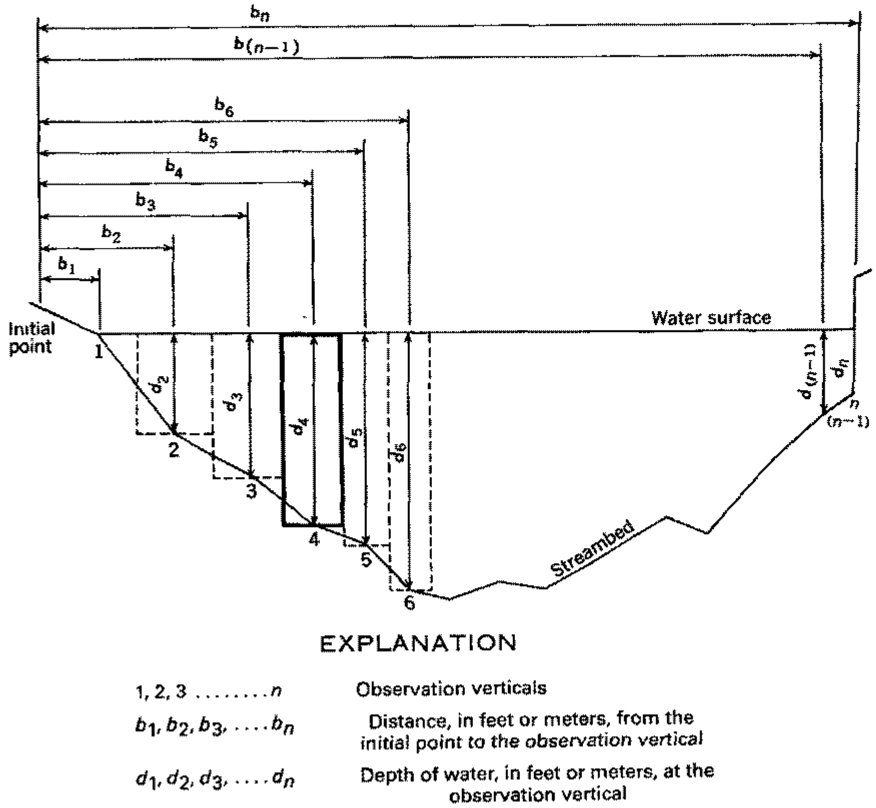


Figure 9 Cross section sketch illustrates depth and distance between verticals that define the area of measurement cells. Velocities measured at these verticals represent the velocity of the cell. (Illustration from USGS Water Supply Paper 2175, pg. 81.)

6.15.10 Observe in figure 9 the discharge of q_1 is zero. This is because the depth of observation point 1 is zero. There may or may not be actual discharge in this half cell on the edge of the cross section. Typically the amount of actual flow here is inconsequential. However the first and last vertical should be placed close to the edge when the depth at the edge is zero. This insures any residual, uncounted flow remains insignificant.

6.15.11 Now observe vertical *n* at right edge of figure 9. Here the edge is a vertical boundary where the depth is not zero and the velocity may or may not be zero.

6.15.12 Because velocity cannot be measured accurately at a vertical boundary, the velocity at the boundary can be estimated by measuring the mean velocity at a distance from the boundary equal to the depth at the boundary (Rantz, 1982).

6.16 <u>Use of a Wading Rod</u>

6.16.1 Ecology's Fresh Water Monitoring Unit uses a standard four foot top setting wading rod in graduated English units. Top setting wading rods have a 1/2-inch hexagonal rod to measure depth. The hexagonal rod is marked by single lines scored in one-tenth foot graduations up the length of the rod. Every one half foot is marked with double lines. At every one foot increment a group of three lines are scored. The top of the hexagonal rod at the base of the rod handle is 4 feet from the base of the rod.

6.16.2 Place the wading rod in the stream such that the round base sits on the streambed. The depth of the water is read on the hexagonal rod. Care should be taken to make sure the depth is read consistent with the incremental marks on the rod as these markings are not numbered. Make sure the correct foot, half-foot, and tenth-foot marks are referenced.

6.16.3 Velocity head or pile up will occur to varying degrees depending on the velocity. If the pile up on the rod is low a depth reading is somewhat easy and one can estimate depths to the nearest 0.01 foot. In higher velocities pile-up and surface bounce will make the depth reading more difficult. Attempt to read the surface by eyeballing the water surface around the rod and estimate where it intersects the rod. To account for bounce try to estimate the average between the top and bottom of the bounce. Depending on the severity of these conditions the depth should be read to the nearest 0.1 or 0.05 depth.

6.16.4 A 3/8-inch diameter round rod is used for setting the position of the current meter to the desired measurement depth of two tenths, six tenths, or eight tenths of total depth at the measurement vertical.

6.16.5 The round rod is engraved with numbered lines extending around the circumference of the rod. The numbered lines correspond to the whole foot increment of the measured depth, for example 1.7 feet.

6.16.6 On the wading rod handle, the numbers 0 through 10 are pressed with corresponding hash marks. These numbers correspond to the tenths of feet measured in addition to the whole feet, for example 1.7 feet. The current meter is set by aligning the numbered lines corresponding to whole feet of the round rod with the appropriate tenths number pressed into the rod handle.

6.16.7 For example if a depth of 1.7 feet was observed, set the meter at six tenths of depth by aligning the 1 foot line on the round rod with the seven tenths mark on the rod handle (figure 10). If the depth can be read to increments less than one tenth of a foot, set the round rod appropriately.

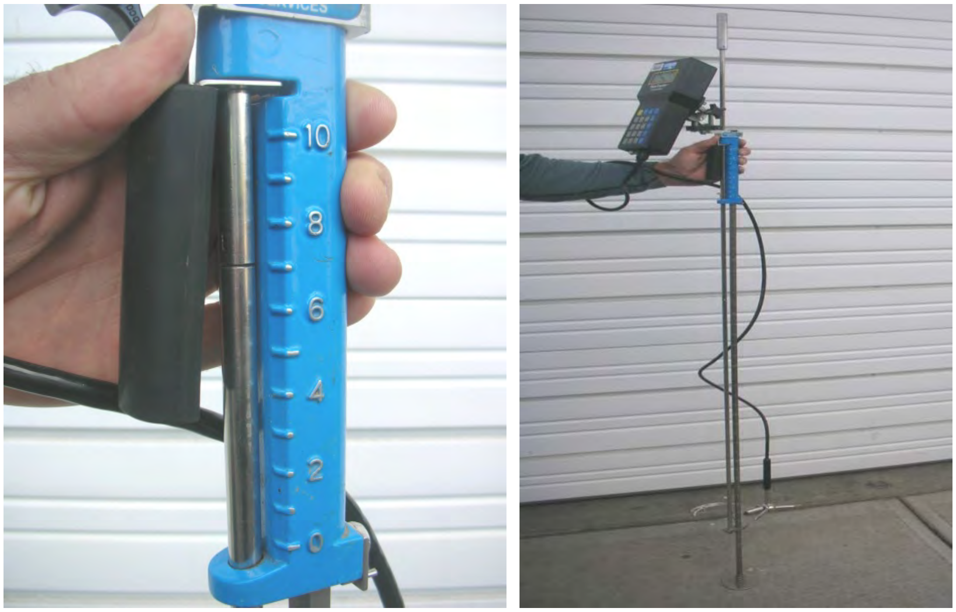


Figure 10 Wading rod with meter set at six tenths of a depth of 1.7 feet. (Photo by Washington Dept. of Ecology)

6.16.8 Meter settings at two tenths, eight tenths, and six tenths of depth means the meter is positioned in the water column at the respective depth setting measured from the surface of the water. The top setting rod is designed to automatically set the meter at six tenths of depth from the water surface.

6.16.9 Described alternatively, when the meter is set at six tenths from the water surface it is also positioned at four tenths of depth from the streambed. This point is important in understanding how to set the rod to measure velocities at two tenths and eight tenths of depth. By dividing the depth by two and setting the meter at that corresponding value, the meter is now set at two tenths depth from the bottom or eight tenths from the water surface. The current meter set at this depth is referred to as an eight tenths velocity sample because the meter is set at eight tenths of the depth from the water surface.

6.16.10 Conversely, if the rod is set at two times the observed depth, the meter is positioned at eight tenths from the bottom and two tenths from the water surface. This current meter setting is referred to as a two tenths velocity sample because the meter is set at two tenths of the depth from the water surface.

7.0 Records Management

7.1 <u>Field Note Forms Archives</u>

7.1.1 All original field discharge measurement notes are stored in central locations at Ecology Headquarters, Regional, and Field Offices.

7.2 Discharge Records in Hydstra Database

7.2.1 All discharge measurement details are recorded and stored electronically to the Hydstra Gauging and Sections databases.

7.2.2 Measurement details stored in the Gaugings database include the stage, discharge, date and time of the measurement. Other details stored in the Gaugings database include average velocity, area, maximum depth and velocity, width, and wetted perimeter.

7.2.3 Cross section details such as vertical locations and bed elevations are stored in the Sections database.

8.0 Safety

8.1 All EAP safety policies are followed and safety is always the top priority when conducting stream discharge measurements. Refer to the EAP Safety Manual, (EAP, 2012) for further information about working in and around streams.

8.2 In all measurement situations never attempt unsafe deployments that may result in injury to staff, or damage to equipment.

8.3 Always consider the safety and traffic situations when measuring from a bridge and take appropriate actions including suspending the measurement if unsafe conditions exist. Consult the EAP Safety Manual for further guidance regarding bridge measurement safety.

8.4 Safely cross the stream in accordance with the guidelines for working in and around streams established in the EAP Safety Manual (EAP, 2010).

9.0 References

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9.1 Burks, T.W., 2009. Standard Operating Procedure (SOP) for Operation of the Sontek® FlowTracker® Handheld ADV®, Version 1.0. Washington State Department of Ecology, Olympia, WA. SOP Number EAP058. http://www.ecy.wa.gov/programs/eap/quality.html

9.3 Environmental Assessment Program, 2012. Environmental Assessment Program Safety Manual, May, 2012. Washington State Department of Ecology, Olympia, WA.

9.4 Holt, Z., Shedd, J.R., 2013. Standard Operating Procedure (SOP) for Operation of Mechanical Velocity Indicators, Version 1.1. Washington State Department of Ecology, Olympia, WA. SOP Number EAP 059. www.ecy.wa.gov/programs/eap/quality.html

9.5 Kennedy, E.J., 1984. Techniques of Water-Resources Investigations of the United States Geological Survey, Chapter A10, Discharge Ratings At Gaging Stations, Book 3, Applications of Hydraulics. United States Geological Survey, Publication.

9.5 Rantz, S.E., et al., 1982. Measurement and Computation of Streamflow: Volume 1. Measurement of Stage and Discharge. United States Geological Survey Water-Supply Paper 2175.

9.6 Shedd, J.R., Springer, C., Clishe, C.J., 2013. Standard Operating Procedure (SOP) for Operation of the Teledyne RD Instruments® Stream-Pro Acoustic Doppler Current Profiler®, Version 1.1. Washington State Department of Ecology, Olympia, WA. SOP Number EAP055. www.ecy.wa.gov/programs/eap/quality.html

9.7 Teledyne RD Instruments®. WinRiver Quick Start Guide. 2007. P/N 957-6230-00.

Appendix A (Discharge Measurement Form Number 040-56)

DEPARTMENT OF ECOLOGY State of Washington

STATE OF WASHINGTON
DEPARTMENT OF ECOLOGY

DISCHARGE MEASUREMENT NOTES

Meas.No. ....
Comp. by.....................
Check by ....

Sta. No. .... Prop. No. ....
Name:..
Date ...., 20 .... Party ....
Width .... Area................. Vel. .... G.H. .... Disch.....................
Method................. No. secs. .... G.H. change .... in .... hrs.
Max Depth. .... Hor. angle coef.............. Wetted Perim............. Meter No....................

GAGE READINGS

Time	TD/WT	Logger	Staff	+/-
REW				
LEW				
WW				
Cell Width				

Type of meter.......................................
Calibration Pre: .... Post: ....
QA form attached Y/N
Vel Unc ....
Depth Unc ....
Overall Unc ....
Wading, cable, ice, boat, upstr., downstr., side bridge .... feet, mile, above, below gage, and...... ....
Check-bar, found ....
changed to .... at ....

Measurement rated excellent (2%), good (5%), fair (8%), poor (over 8%), based on following conditions:
Cross section..
Flow... ....
Control...
....Photo taken Y / N
Gage...
Weather...
Other...
Remarks...
....
....
....
....

Zero flow = GH ___________________ -depth at control ____________ = ______________ft.

ECY 040-56 (Rev. 12/07)

.0 .10 .20 .30 .40 .50 .60 .70 .75

River at –

	Dist. from initial point	VELOCITY						
		Depth	.6	.6	.8	.8	.2	.2
1		REW @						
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								
15								
16								
17								
18								
19								
20								
21								
22								
23								
24								
25								
26								
27								
28								
29								
30								

.80 .85 .90 .92 .94 .96 .97 .98 .99 1.00 .99 .98 .97 .96 .94 .92 .90 .85 .80

.0 .10 .20 .30 .40 .50 .60 .70 .75

Vehicle and Equipment Checklist

Standard Vehicle Equipment:

This equipment should be present anytime the vehicle is used.

- Cell Phone and Charger

Vehicle Folder containing

- Mileage Logs
- Emergency Information
- Fuel Card
- Maps

Safety Equipment

- First Aid Kit
- MUTCD compliant Safety Vests (2)
- CG Approved PFD (1 per person)
- PFD CO_2 Refill
- Road Cones
- Signs
- Hard Hats (2)
- Orange Strobe

Tools / Other

- Mechanic's Toolbox
- Shovel
- Loppers/Clippers/Machete
- Tire Chains
- 2- 150 ft. Ropes
- Spare Key
- Jack, jack handle, adequate spare
- Flashlight
- Lighter
- Electrical Tool Box
- Pens
- Pencils
- Note Paper
- Flagging Tape
- Orange Spray Paint
- Spare Bucket

Standard Flow Gear

Flow Box:

- Weighted Tape for Tape Down
- Tag Line
- 300 ft. Transect Tape
- Line Clamps
- Swoffer Kit w/ Cables and Fans
- Swoffer Meter
- Bridge Depth Sounding Correction Sheets (2/10, 6/10, 8/10's)
- Survey Pins and Hammer
- Flow Tracker
- Wading rod
- Laser Level
- Stadia Rod
- Thermistor
- Spare Batteries for All Devices
- Battery Chargers
- Discharge Measurement Sheets

Station Visit

- Station Visit Data Flash Card
- Multi-meter
- Logger Menu Flow Chart
- Desiccant
- Station Key
- USGS key
- Other Keys as needed
- Appropriate DCP Batteries

ADCP Gear

- ADCP Unit
- PDA (CHECK BATTERY STATUS)
- SD card for PDA
- Tow Ropes and Carabiners
- ADCP Data Sheet

Bridge Gear (If Needed)

- Lead Flow Weights, all sizes
- Bridge Board
- T-bar
- Reel w/ Swoffer Cable

3-Wheel Crane

- Reel
- Crane Assembly

4-Wheel Crane

- HS Meter Box
- Props
- Meter Body w/Fiber-Fin
- Cleaning Soln.
- Lubricant
- Reel
- Crane Assembly/Boom
- Counterweights
- Wheel Chocks

Personal Equipment

- Water
- Food
- Dry Clothes
- Rain Gear
- Sunscreen
- Gloves
- Waders/Hip Boots
- Up to Date Ratings Sheets
- Maps/Station Directions
- Notebook w/ Extra Data Sheets

Washington State Department of Ecology

Environmental Assessment Program

Standard Operating Procedures for Correction of Continuous Stage Records Subject to Instrument Drift, Analysis of Instrument Drift, and Calculation of Potential Error in Continuous Stage Records

Version 1.0

Authors – James R. Shedd and Chuck Springer
Date -

Reviewer -Mitch Wallace
Date –

QA Approval - William R. Kammin, Ecology Quality Assurance Officer
Date -

EAP No. EAP082

Please note that the Washington State Department of Ecology's Standard Operating Procedures (SOPs) are adapted from published methods, or developed by in-house technical and administrative experts. Their primary purpose is for internal Ecology use, although sampling and administrative SOPs may have a wider utility. Our SOPs do not supplant official published methods. Distribution of these SOPs does not constitute an endorsement of a particular procedure or method.

Any reference to specific equipment, manufacturer, or supplies is for descriptive purposes only and does not constitute an endorsement of a particular product or service by the author or by the Department of Ecology.

Although Ecology follows the SOP in most instances, there may be instances in which Ecology uses an alternative methodology, procedure, or process.

SOP Revision History

Revision Date	Rev	Summary of changes	Sections	Reviser(s)
10/5/2012	1.0	New SOP	all	Kammin

1.0 Purpose and Scope

1.1 This Environmental Assessment Program (EAP) Standard Operating Procedure (SOP) describes methods of correcting continuous stage data records subject to instrument drift. This document explains methods of identification, analysis, and management of various types of instrument drift occurring in continuous stage records. Methods of calculation of potential error caused by instrument drift are also discussed.

2.0 Applicability

2.1 EAP staff will follow this Standard Operating Procedure when correcting stage records to match gage height observations with corresponding points in the stage record.

2.2 Staff will follow the methods presented in this document to identify and analyze instrument drift. Refer to this document when calculating potential error introduced to daily flow values caused by logger drift.

3.0 Definitions

3.1 Primary Gage Index (PGI)—The base gage for the station to which the recording gage is directly referenced. The primary gage index is the most stable and reliable gage at a site. All other gages at a station are considered secondary.

3.2 Gage Height—The water surface level, usually measured in hundredths of a foot on a readable stationary gage.

3.3 Calibration—The check of a measuring instrument against an accurate standard to determine any deviation and correct for errors. For purposes of the following discussions regarding calibration, the 'measuring instrument' refers to the data logger. The 'accurate standard' refers to the gage height of the PGI. 'Correct for errors' in this case does not necessarily mean direct correction of the instrument in the field, rather the correction or accounting of errors in the stage record resulting from drift.

3.4 Potential Error—A calculated percentage expressing the highest probable error in the stage record for a designated time period, usually a day or a year.

3.5 Drift— An undesired change in instrument output over time that is not a function of real changes in water surface elevation (Freeman, et al, 2004).

3.6 Zero Drift— A shift between an initial calibration (a point at which the record matches the PGI observation) and later calibrations where the differences between PGI observations and instrument output are equal (Freeman, et al, 2004).

3.7 Stable Drift—A zero drift condition in which the calibration shift has stabilized over time and is reflected by a consistent difference between true gage height and instrument output. Note that stable drift can contain relatively small errors due to minor variations between gage height and instrument output.

3.8 Data Shift—A factor used to compensate for pressure transducer drift that represents the difference between logged and observed stage values. These shift factors adjust the stage record to individual gage height observations. Data shifts are applied automatically to a data set whenever a report is generated from Hydstra™.

3.9 Sensitivity Drift— A change in slope of the best fit straight line between an initial calibration and later calibrations where the differences between true gage height and instrument output changes linearly (Freeman, et al, 2004). Sensitivity drift exhibits a clear pattern in the data, trending either upward (positive drift) or downward (negative drift) as stage increases or decreases, with a strong correlation between corrected stage and data shift.

3.10 Random Drift— A condition in which drift occurs, but a specific type or cause of drift cannot be identified. The amount of drift or the distance between corresponding points of initial and later calibrations are not consistent and do not change linearly. It is assumed random drift occurs incrementally over time between calibrations.

3.11 Measurand— The value of the measured physical property. For purposes of this discussion the measurand value is the gage height of a body of water.

3.12 Aliased Data Set—In the context of this SOP, a raw stage dataset where the Hydstra™ parameter reference is changed to that of corrected stage without applying data shifts. This "aliased" data set is then compared to the original raw data set, to which data shifts are applied, to assess the magnitude of potential drift error.

4.0 Personnel Qualifications/Responsibilities

4.1 Users of this document will typically work in the Hydrogeologist job classification. Mostly those with Principle Investigator or Basin Lead responsibilities will apply the procedures presented herein. Sufficient training in the Hydstra™ data management software is required to perform the operations in this SOP.

5.0 Equipment, Reagents, and Supplies

5.1 An Ecology issued computer with network and web access is required.

5.2 Access to Hydstra™ Time Series Management software is required.

6.0 Summary of Procedure

6.1 Correction of Instrument Drift

6.1.1 At the time a flow monitoring station is initially installed the datalogger and transducer are calibrated such that the reported stage matches the water level read from the PGI. This equipment detects and reports fluctuating differences in gage height as flow increases or decreases at predetermined time intervals (typically 15 minutes). Over time the value reported by the instrument may drift from the actual water level at the PGI resulting in an inaccurate stage record. This condition requires correction if the drift exceeds the variability (water surface bounce) in the water level observed at the PGI. If the record goes uncorrected, erroneously reported discharge values will result.

6.1.2 Depending on the type and severity of the drift, the data logger may be recalibrated in the field at the time of the gage height observation. However, field recalibrations should remain limited to circumstances when drift is severe or when damage or movement of station infrastructure has occurred. If consistently severe random drift persists, take steps to mitigate the situation such as increasing sampling times, installing bubble chambers, and programming regular auto-purging on bubbler systems. Clean and, if necessary, replace submersible transducers. Check the mounting and calibration of radar levels. If severe drift conditions continue consider repositioning infrastructure or moving the entire station to a more suitable location.

6.1.3 The underlying assumption in most cases of instrument drift is that it occurs incrementally over time. This assumption holds that the least amount of drift is found at the start of the data set or the initial calibration and progresses over time until reaching the next calibration point where the amount of drift is presumed greatest.

6.1.4 Likewise the same assumption holds in the correction of logger drift. Adjustments to the data set are made on a time-weighted basis such that the gap between the logger record and observed gage heights closes incrementally from the start of the data set to the end of the data set.

6.1.5 There are two ways corrections are applied to data sets in which drift has occurred: Time-weighted filter adjustments and data shift adjustments.

6.1.5.1 Time-weighted Filter Adjustments

6.1.5.1.1 Time-weighted filter adjustments are applied directly to the raw stage record. This method is largely outdated and no longer the preferred procedure. This method was discontinued beginning with the 2008 water year and is primarily used only for data records prior to that year.

6.1.5.1.2 The time-weighted filter adjustment method uses explicit changes to the data set to correct the continuous data incrementally from one observed stage height to the next. See Chapter 4 of the Hydstra User's Manual for detailed instructions on how to make time-weighted data adjustments.

6.1.6 Data Shift Adjustments

6.1.6.1 The current method for correcting stage height data uses the Hydstra™ data shift function to apply shift factors to correct for pressure transducer drift. This method has significant advantages over the previous method, both in terms of ease of use and immediacy of results. Data shift capabilities permit corrections to telemetered stage records immediately upon entry of independent PGI observations into Hydstra™. These corrections are automatically applied to both the archive and telemetry data records.

6.1.6.2 The use of data shifts renders the time-weighted adjustments for the most part unnecessary. The new process for correcting continuous data is detailed in the Hydstra User's Manual addendum "Preparing Continuous Data and Data Shifts for Annual Review".

6.2 Analysis of Logger Drift

6.2.1 Prior to submittal of annual discharge records for senior-level review carefully analyze the logger record as well as the record of corrections to determine the types of drift occurring through the record. The type of drift will affect how the final logger record is edited, how daily error percentages are determined, as well as influence the overall evaluation of the quality of the discharge record.

6.2.2 There are four basic types of logger drift; random, sensitivity, stable, and zero drift. Figure 1 illustrates sensitivity and zero drift.

6.2.2.1 Random drift is characterized by contiguous differences between the record and PGI observations that are not consistent in their magnitude. Random drift does not meet the requirements of stable drift described below. The differences between record and PGI observations are not part of a linear relationship consistent with sensitivity drift, also described below.

6.2.2.2 Random drift is adjusted in the final data record by applying either time-weighted filter adjustments or data shifts.

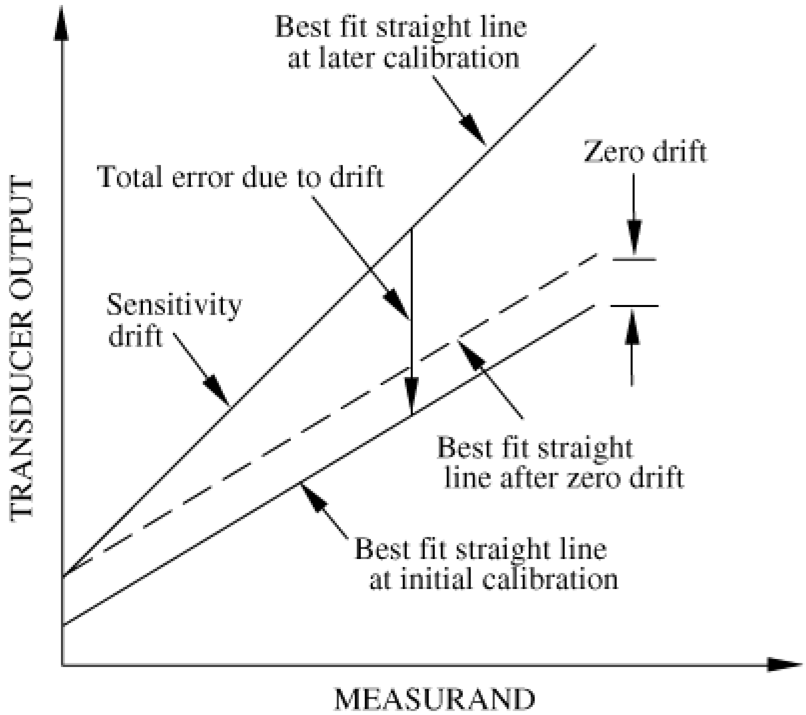

Figure 1. Illustration of zero and sensitivity drift. (Illustration from USGS Publication, Use of Submersible Pressure Transducers in Water-Resources Investigations, pg. 13.)

6.2.2.3 Sensitivity Drift Analysis and Correction

6.2.2.3.1 In preparation for the annual review process, the pressure transducer drift should be analyzed using linear regression to determine whether or not sensitivity drift is occurring at each station. This can be done by regressing the corrected stage values against the data shifts.

Zero Drift: Sensitivity Drift (mild):

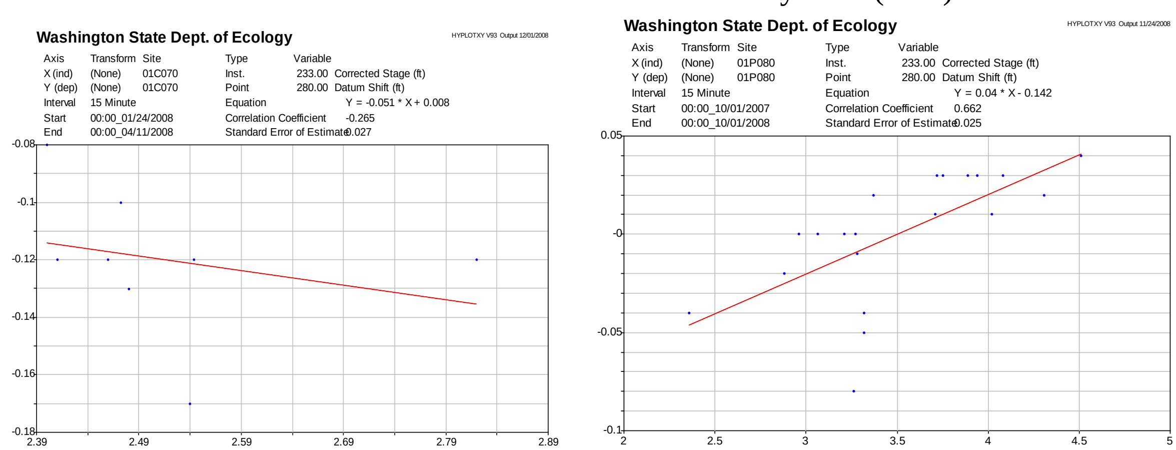

Figure 2. Examples of zero drift and sensitivity drift at Ecology streamgaging stations.

6.2.2.3.2 Sensitivity drift is evidenced by a clear pattern in the data, trending either upward (positive drift) or downward (negative drift) as stage increases, and a strong correlation ($r \geq 0.80$) between corrected stage and data shift.

6.2.2.3.3 If sensitivity drift is found at a station, data shifts alone may not be adequate to correct it, as they may tend to underestimate the magnitude of drift at high flows. In cases of more extreme sensitivity drift, the results of the stage vs. data shift regression can be used to derive a “drift curve” that varies the magnitude of drift by stage height. The regression equation for the drift curve represents the magnitude of the drift corrections as they vary by stage. This record of corrections must be added to the original data record to correct for sensitivity drift. See the Hydstra Users Manual for detailed instructions on how to do this. The corrected data can then be further adjusted to the manual observations using time-weighted adjustments or a revised set of data shifts that reflect the differences between the corrected datalogger values and the manual observations. This method should only be used to correct sensitivity drift that is consistent in occurrence, as evidenced by a high correlation coefficient (≥ 0.80) in the stage vs. data shift regression.

6.2.2.4 Stable drift Analysis

6.2.2.4.1 Stable drift occurs when the difference between recorded stages and PGI observations remains steady and nearly equal over the course of two or more site visits.

6.2.2.4.2 Neglecting to address stable drift can result in substantial inaccuracies of published annual potential error determinations as well as falsely reporting daily flows as estimates, unreliable estimates, or erroneously cause un-reported daily flows.

6.2.2.4.3 Consider periods of stable drift when assessing potential error caused by instrument drift. We define stable drift as a set of two or more contiguous differences between logger recordings and gage height observations where the range of differences between highest and lowest exceeds no more than 0.03 feet and the standard deviation of the differences do not exceed 0.015 feet.

6.2.2.4.4 In order to identify stable drift, examine the Data Review Worksheet comparing the aliased stage record to observed gage heights. To do this, export the raw data set to a new work file in the Hydstra™ Data Workbench, and use the "alias" feature to save the new data set as corrected stage in feet (Hydstra™ variable 233) without actually performing any mathematical corrections. Use the aliased raw data set in creating the worksheet to avoid the data shift corrections applied by Hydstra™. Look for strings of contiguous differences between gage height observations and the logger record where the range of differences is less than or equal to 0.03 ft. Calculate the individual standard deviation of each contiguous set of differences. Consider the string of differences as a period of stable drift if the standard deviation is less than or equal to 0.015 ft. and the range is less than or equal to 0.03 ft.

6.3 Potential Error Calculation

6.3.1 In finalizing water year data we must accurately determine the amount of potential error introduced to the record from instrument drift.

6.3.2 To determine potential error due to instrument drift, calculate daily differences in predicted discharge between the aliased raw record and the original raw record. Do not use the final or archived record. Directly comparing the final record against the raw record may not produce a valid comparison or an accurate drift error assessment, as there may be changes to the archive data set that are not appropriate to quantify as drift.

6.3.3 Do not include erroneously recorded data due to instrument damage, low battery voltage, anomalous spikes, and the like in the drift assessment. In addition, exclude periods of icing conditions from the assessment. For periods of backwater condition, if a valid rating curve exists for the backwater period, include the continuous data for that period in the assessment. Otherwise, exclude these data from the assessment. While these circumstances may still produce a correct record of gage height, in the absence of a valid stage-discharge relationship the error calculations will be incorrect.

6.3.4 Stage data influenced by tidal spikes can be treated the same as normal stage data. While these spikes do represent a temporary breakdown of the stage-discharge relationship, a comparison of tidally influenced stations in Ecology's streamflow monitoring network showed the impact is less than 2% of total discharge.

6.3.5 The procedure for producing raw and aliased raw discharge records is detailed in the Hydstra User's Manual addendum "Preparing Continuous Data and Data Shifts for Annual Review".

6.3.6 In order to preclude erroneous data from reporting assign a quality code of 200 to any erroneously recorded data in the raw data set, as well as to periods with invalid stage and discharge relationships (i.e., backwater, ice-impacted, etc.) If erroneous data is allowed to report, the resulting calculated error does not reflect instrument drift even if data points match and the percent error is zero. Zero percent values computed from erroneous stage data and subsequently calculated in the annual drift error will cause an underestimation of the annual drift error. Erroneous data that has been quality coded 200 will show up on the daily discharge table as a blank value and excluded from all calculations.

Calculate the potential error percentage in the following form:

$$e = \frac{|y-x|}{x} * 100$$

Where e = the absolute value of the percent error between daily discharge reported from the raw record and discharge reported the aliased record. Thus,

x= mean daily reported discharge from the raw record (with data shifts applied) and

y= mean daily reported discharge from the aliased raw record.

6.3.7 Continuous stage data collected during periods of unstable drift should be quality coded based on the results of the logger drift error assessment. For this, a tiered approach is used whereby the difference and percent difference between raw and adjusted data sets are used to determine the appropriate quality code:

Tier	***% Diff***		***Diff Q***	***QC***
1	0-20%	OR	<0.5	2
2	≥20%	AND	≥0.5	50
3	≥50%	AND	≥5	164
4	≥100%	AND	≥50	179

6.3.7.1 Data must meet both the %Diff and Diff Q criteria for a tier to be coded according to that tier. If data meets one, but not both criteria, it falls into the tier above. For example, if a day has a difference of 100% and a difference in Q < 5 cfs, that meets the criteria for tier 2, and should thus be coded 50. If the difference was >100% and the difference in Q was greater than 5 cfs but less than 50 cfs, it would get a code 164. In order for the data to be coded 179, it would have to have a percent difference greater than 100% and a difference in discharge greater than 50 cfs.

6.3.7.2 The quality codes should be applied on a daily basis. If a day meets the criteria for a given tier, all stage values for that day should be coded according to that tier.

6.3.7.3 For a detailed description on how to quality code the continuous data, refer to the addendum to the Hydstra Users Manual titled "Preparing Continuous Data and Data Shifts for Annual Review."

6.3.8 Stable Drift Error

6.3.8.1 During periods of identified stable drift, the error percentages calculated in the initial assessment are likely incorrect and could significantly exaggerate the true error. Change initial daily error percentages to reflect minor variations between observed gage heights and the data record during stable drift periods. However, do not change the initial error percentage to zero unless the error is in fact zero. Assigning a value of zero does not adequately address the small error found in most stable drift periods and results in an under-estimation of the annual error.

6.3.8.2 To address these small differences between observed gage heights and the data record during periods of stable drift, assign a pre-calculated default average error value of 2.4 percent to each daily discharge unless the original calculated error is less than 2.4 percent. Alternatively, if deemed more appropriate, calculate the error value for individual stable drift periods rather than using the pre-calculated 2.4 percent. The method used to derive the pre-calculated average error of 2.4% is detailed in Appendix A.

6.3.8.3 To determine true stable drift error of a contiguous period as an alternative to assigning the 2.4 percent average error, calculate mean percent differences between discharges corresponding to gage height observations, against discharges corresponding to offset logger values. An offset logger value is the recorded logger value (in feet) minus the average of the differences between gage height observations (in feet) and corresponding logged values throughout the stable drift period.

Stable drift error takes the form: U = $\frac{\sum_{n}^{i=1}\left|\left(\frac{x-y}{x}\right)\right|_i}{n} * 100$

Where U = mean error for the stable drift period expressed in percent
x= discharge corresponding to an observed gage height
y= discharge corresponding to offset logger value
n=number of x and y pairs in the stable drift period.

Offset logger value is expressed in the form ∅= r- $\frac{\sum_{n}^{i=1}(r-g)_i}{n}$

Where Ø=offset logger value (in feet)
r=raw logged stage value (in feet)
g=observed gage height value (in feet)
n=number of r and g pairs in stable drift period.

7.0 Records Management

7.1 Several databases in the Hydstra™ Time Series Management Software store continuous stage records, instantaneous gage height observations, and applied data shifts.

7.2 It is possible to compile Data Review Worksheets at any time as these are produced from stored records in the Hydstra™ Time Series Management Software.

7.3 Sensitivity drift regression run in the Hydstra™ regression analysis package HYPLOTXY are saved in a graphics format such as jpeg.

7.4 Typically staff will store analyses of instrument drift including stable drift analysis in Microsoft© Excel® workbooks.

7.5 All electronic files and Hydstra™ related materials are saved to a folder on a network server. The contents of this server are backed up daily to prevent data loss.

8.0 Quality Control and Quality Assurance Section

8.1 Senior staff, through the senior-level review process evaluates all submitted records and data analyses materials for accuracy and compliance with the methods presented in this document.

9.0 Safety

9.1 Most of the work described in this document takes place in an office setting. Staff will follow building and office safety policies and procedures when working in the office. Refer to the agency safety manual (Washington Department of Ecology, 2008) for information regarding building and office safety.

9.2 When collecting streamflow information in the field, staff will follow all EAP safety policies and guidelines. Refer to the EAP Safety Manual (EAP, 2010) for further information.

10.0 References

10.1 Freeman, L., et al, 2004. Use of Submersible Pressure Transducers in Water-Resources Investigations: Chapter A of Book 8, Instrumentation Section A Instruments for Measurement of Water Level. United States Geological Survey, Publication.

10.2 Environmental Assessment Program, 2010. Environmental Assessment Program Safety Manual, September, 2010. Washington State Department of Ecology, Olympia, WA. http://aww.ecology/programs/eap/Safety/Safety1.html

10.3 Washington Department of Ecology, 2008. Washington Department of Ecology Safety Program Manual, July, 2008. Washington State Department of Ecology, Olympia, WA. http://aww.ecology/services/es/safety/safety_web/safety_manual.htm

Appendix A

The 2.4 percent error value is the mean of a subset consisting of 22 of 31 original samples empirically identified as periods of stable drift. The criteria of range (0.03 ft.) and standard deviation (0.015 ft.) are the respective averages of the 31 sample sets. As a result, 22 of the samples met or exceeded the average range and standard deviation of the 31 samples. The 22 samples meeting the criteria yielded a mean error of 2.4 percent.

The true error of any stable drift period may be higher or lower than the 2.4 percent figure. The high and low error values in the sample set were 8.4 and 0.4 percent respectively. The standard deviation of the 2.4 percent average was 1.9 and the median error was 2.1 percent.

Table 1 presents the analysis used to derive the thresholds associated with identifying stable drift.

Table 1. Stable Drift Analysis

Date	Log St.	Log St. Q	Obs St.	Obs St. Q	Diff Ft.	Avg.Diff Ft.	Log-Avg. Diff Ft.	Log-Avg. Diff Ft. Q	% Diff	Diff Ft. STDEV	Range	Notes
Sample 1	**35L050 (from rating 10)**											
2/19/2008	5.73	27.5	4.96	10.6	0.77	0.78	4.95	10.4	**1.89**	**0.014**	**0.02**	
2/28/2008	5.69	26.4	4.9	9.11	0.79	0.78	4.91	9.36	**2.74**			
								Average	**2.32**			
Sample 2	**01A140 (from rating 5)**											
10/11/2007	7.61	2821	7.01	1688	0.6	0.61	7	1673	**0.89**	**0.014**	**0.02**	
10/25/2007	8.13	4433	7.51	2593	0.62	0.61	7.52	2615	**0.85**			
								Average	**0.87**			
Sample 3	**01A140 (from rating 5)**											
11/8/2007	7.34	2250	6.56	1060	0.78	0.8	6.54	1035	**2.36**	**0.028**	**0.04**	
11/15/2007	7.49	2551	6.67	1200	0.82	0.8	6.69	1226	**2.17**			
Sample 4	**01A140 (from rating 2)**											
12/13/2007	8.21	4776	6.42	966	1.79	1.80	6.41	956	**1.04**	**0.013**	**0.03**	
12/18/2007	8.16	4559	6.36	909	1.8	1.80	6.36	909	**0.00**			
1/3/2008	8.06	4151	6.26	823	1.8	1.80	6.26	823	**0.00**			
1/24/2008	7.84	3418	6.02	649	1.82	1.80	6.04	661	**1.85**			
								Average	**0.72**			
Sample 5	**01A140 (from rating 2)**											
2/6/2008	5.93	595	5.81	531	0.12	0.10	5.83	540	**1.69**	**0.019**	**0.05**	
2/14/2008	6.39	937	6.29	848	0.1	0.10	6.29	848	**0.00**			
2/28/2008	6.2	775	6.1	700	0.1	0.10	6.10	700	**0.00**			
3/13/2008	6.64	1198	6.56	1109	0.08	0.10	6.54	1087	**1.98**			
3/19/2008	6.32	874	6.2	775	0.12	0.10	6.22	791	**2.06**			
4/3/2008	5.99	630	5.92	589	0.07	0.10	5.89	572	**2.89**			
4/10/2008	6.03	655	5.91	583	0.12	0.10	5.93	595	**2.06**			
4/24/2008	6.07	680	5.97	618	0.1	0.10	5.97	618	**0.00**			

Date	Log St.	Log St. Q	Obs St.	Obs St. Q	Diff Ft.	Avg.Diff Ft.	Log-Avg. Diff Ft.	Log-Avg. Diff Ft. Q	% Diff	Diff Ft. STDEV	Range	Notes
Sample 6	**01A140 (from rating 2)**											
4/29/2008	6.93	1571	6.92	1556	0.01	0.03	6.90	1528	**1.80**	**0.017**	**0.03**	
4/30/2008	6.79	1381	6.75	1330	0.04	0.03	6.76	1342	**0.90**			
5/13/2008	6.72	1293	6.68	1245	0.04	0.03	6.69	1257	**0.96**			
Sample 7	**01C070 (from rating 4)**											
10/7/2007	2.19	21.6	2.16	20	0.03	0.03	2.16	20	**0.00**	**0.013**	**0.04**	
10/25/2007	2.8	62.5	2.76	59.2	0.04	0.03	2.77	60	**1.35**			
11/1/2007	2.38	33.9	2.36	32.8	0.02	0.03	2.35	32.3	**1.52**			
11/8/2007	2.43	36.6	2.42	36.1	0.01	0.03	2.40	35	**3.05**			
11/8/2007	2.43	36.6	2.4	35	0.03	0.03	2.40	35	**0.00**			
11/16/2007	3.28	113	3.25	109	0.03	0.03	3.25	109	**0.00**			
11/16/2007	3.3	116	3.25	109	0.05	0.03	3.27	112	**2.75**			
								Average	**1.24**			
Sample 8	**01C070 (from rating 4)**											
12/4/2007	3.41	131	3.31	117	0.1	0.07	3.34	121	**3.42**	**0.019**	**0.05**	
12/6/2007	2.97	78	2.89	70.4	0.08	0.07	2.90	71.3	**1.28**			
12/13/2007	2.5	40.8	2.44	37.2	0.06	0.07	2.43	36.6	**1.61**			
12/17/2007	2.81	63.3	2.76	59.2	0.05	0.07	2.74	57.6	**2.70**			
1/3/2008	2.82	64.2	2.75	58.4	0.07	0.07	2.75	58.4	**0.00**			
Sample 9	**01C070 (from rating 5)**											
3/19/2008	2.66	64.7	2.55	57	0.11	0.12	2.54	56.3	**1.23**	**0.010**	**0.02**	
4/3/2008	2.53	55.7	2.41	47.5	0.12	0.12	2.41	47.5	**0.00**			
4/10/2008	2.61	61.1	2.48	52.4	0.13	0.12	2.49	53.1	**1.34**			
								Average	**0.85**			
Sample 10	**01C070 (from rating 2)**											
10/10/2006	0.84	5.05	0.83	4.87	0.01	0.01	0.83	4.87	**0.00**	**0.005**	**0.01**	
10/19/2006	0.88	5.8	0.87	5.61	0.01	0.01	0.87	5.61	**0.00**			
10/23/2006	0.86	5.42	0.86	5.42	0	0.01	0.85	5.23	**3.51**			

Date	Log St.	Log St. Q	Obs St.	Obs St. Q	Diff Ft.	Avg.Diff Ft.	Log-Avg. Diff Ft.	Log-Avg. Diff Ft. Q	% Diff	Diff Ft. STDEV	Range	Notes
10/25/2006	0.87	5.61	0.87	5.61	0	0.01	0.86	5.42	**3.39**			
10/31/2006	0.91	6.42	0.9	6.21	0.01	0.01	0.90	6.21	**0.00**			
								Average	**1.38**			
Sample 11	**01C070 (from rating 3)**											
11/20/2006	2.4	79.6	2.26	60	0.14	0.14	2.26	60	**0.00**	**0.015**	**0.03**	
12/4/2006	2.2	52.4	2.08	39.3	0.12	0.14	2.06	37	**5.85**			
12/12/2006	2.93	178	2.78	146	0.15	0.14	2.79	148	**1.37**			
								Average	**2.41**			
Sample 12	**01C070 (from rating 3)**											
12/19/2006	2.63	117	2.36	73.7	0.27	0.26	2.38	76.6	**3.93**	**0.021**	**0.03**	
1/2/2007	2.88	167	2.64	119	0.24	0.26	2.63	117	**1.68**			
Sample 13	**01C070 (from rating 3)**											
1/18/2007	2.1	41.4	2.17	48.9	-0.07	-0.06	2.16	47.8	2.25	0.012	0.02	
1/23/2007	2.59	110	2.64	119	-0.05	-0.06	2.65	121	**1.68**			
2/1/2007	2.03	33.9	2.1	41.4	-0.07	-0.06	2.09	40.4	**2.42**			
								Average	**2.12**			
Sample 14	**01A140 (from rating 3)**											
10/10/2006	4.11	302	4.09	292	0.02	0.02	4.09	292	**0.00**	**0.015**	**0.03**	
10/19/2006	4.26	377	4.26	377	0	0.02	4.24	367	**2.65**			
10/25/2006	4.2	348	4.17	332	0.03	0.02	4.18	337	**1.51**			
								Average	**1.39**			
Sample 15	**01A140 (from rating 2)**											
12/12/2006	7.29	2157	7.5	2572	-0.21	-0.22	7.51	2593	**0.82**	**0.020**	**0.06**	
12/19/2006	6.84	1447	7.1	1829	-0.26	-0.22	7.06	1765	**3.50**			
1/2/2007	7.89	3561	8.1	4311	-0.21	-0.22	8.11	4351	**0.93**			
1/9/2007	7.02	1703	7.24	2067	-0.22	-0.22	7.24	2067	**0.00**			
1/18/2007	6.33	882	6.54	1087	-0.21	-0.22	6.55	1098	**1.01**			

Date	Log St.	Log St. Q	Obs St.	Obs St. Q	Diff Ft.	Avg.Diff Ft.	Log-Avg. Diff Ft.	Log-Avg. Diff Ft. Q	% Diff	Diff Ft. STDEV	Range	Notes
1/23/2007	7.08	1797	7.29	2157	-0.21	-0.22	7.30	2175	**0.83**			
2/1/2007	6.26	823	6.47	1015	-0.21	-0.22	6.48	1025	**0.99**			
2/13/2007	6.37	918	6.58	1131	-0.21	-0.22	6.59	1142	**0.97**			
2/20/2007	7.2	1997	7.46	2488	-0.26	-0.22	7.42	2407	**3.26**			
3/1/2007	6.25	815	6.45	995	-0.2	-0.22	6.47	1015	**2.01**			
3/6/2007	6.42	966	6.64	1198	-0.22	-0.22	6.64	1198	**0.00**			
Sample 16	**28C110 (from rating 1)**											
12/12/2006	4.27	2.75	4.35	4.49	-0.08	-0.07	4.34	4.31	**4.01**	**0.014**	**0.02**	
12/19/2006	4.28	2.98	4.34	4.31	-0.06	-0.07	4.35	4.49	**4.18**			
								Average	**4.09**			
Sample 17	**28C110 (from rating 1)**											
8/21/2008	4.31	3.68	4.43	6.17	-0.12	-0.15	4.46	6.91	**11.99**	**0.021**	**0.06**	
8/26/2008	4.2	1.5	4.35	4.49	-0.15	-0.15	4.35	4.49	**0.00**			
9/9/2008	4.13	0.715	4.31	3.68	-0.18	-0.15	4.28	2.98	**19.02**			
9/23/2008	4.16	1.04	4.33	4.12	-0.17	-0.15	4.31	3.68	**10.68**			
9/24/2008	4.15	0.925	4.31	3.68	-0.16	-0.15	4.30	3.43	**6.79**			
10/6/2008	4.24	2.15	4.39	5.27	-0.15	-0.15	4.39	5.27	**0.00**			
10/23/2008	4.17	1.14	4.3	3.43	-0.13	-0.15	4.32	3.94	**14.87**			
Sample 18	**28C110 (from rating 1)**											
5/18/2009	4.52	8.58	4.46	6.91	0.06	0.06	4.46	6.91	**0.00**	**0.008**	**0.02**	
5/18/2009	4.5	7.99	4.45	6.66	0.05	0.06	4.44	6.42	**3.60**			
6/1/2009	4.45	6.66	4.39	5.27	0.06	0.06	4.39	5.27	**0.00**			
6/1/2009	4.45	6.66	4.38	5.06	0.07	0.06	4.39	5.27	**4.15**			
								Average	**1.94**			
Sample 19	**32A120 (from rating 12)**											
6/12/2008	4.7	711	4.48	617	0.22	0.24	4.46	609	**1.30**	**0.011**	**0.03**	
6/16/2008	4.16	495	3.94	421	0.22	0.24	3.92	414	**1.66**			
6/19/2008	3.76	365	3.53	299	0.23	0.24	3.52	296	**1.00**			
6/26/2008	3.06	181	2.83	131	0.23	0.24	2.82	129	**1.53**			

Date	Log St.	Log St. Q	Obs St.	Obs St. Q	Diff Ft.	Avg.Diff Ft.	Log-Avg. Diff Ft.	Log-Avg. Diff Ft. Q	% Diff	Diff Ft. STDEV	Range	Notes
7/3/2008	2.55	75.9	2.3	42.4	0.25	0.24	2.31	43.6	**2.83**			
7/10/2008	2.21	33.3	1.97	14.5	0.24	0.24	1.97	14.5	**0.00**			
7/17/2008	2.16	28.8	1.91	11.5	0.25	0.24	1.92	11.9	**3.48**			
7/23/2008	2.33	45.9	2.08	21.8	0.25	0.24	2.09	22.6	**3.67**			
7/31/2008	2.23	35.2	1.99	15.7	0.24	0.24	1.99	15.7	**0.00**			
8/7/2008	2.23	35.2	1.98	15.1	0.25	0.24	1.99	15.7	**3.97**			
8/14/2008	2.19	31.5	1.94	12.9	0.25	0.24	1.95	13.4	**3.88**			
8/21/2008	2.45	61.5	2.2	32.4	0.25	0.24	2.21	33.3	**2.78**			
8/28/2008	2.14	26.9	1.89	10.6	0.25	0.24	1.90	11	**3.77**			
9/4/2008	2.34	47.1	2.1	23.4	0.24	0.24	2.10	23.4	**0.00**			
9/10/2008	2.31	43.6	2.07	21.1	0.24	0.24	2.07	21.1	**0.00**			
9/18/2008	2.31	43.6	2.06	20.4	0.25	0.24	2.07	21.1	**3.43**			
9/25/2008	2.55	75.9	2.3	42.4	0.25	0.24	2.31	43.6	**2.83**			
								Average	**2.13**			
Sample 20	**32A120 (from rating 12)**											
10/3/2008	2.43	58.9	2.18	30.7	0.25	0.25	2.18	30.7	**0.00**	**0.004**	**0.01**	
10/10/2008	2.42	57.7	2.17	29.8	0.25	0.25	2.17	29.8	**0.00**			
10/17/2008	2.35	48.3	2.1	23.4	0.25	0.25	2.10	23.4	**0.00**			
10/21/2008	2.32	44.7	2.07	21.1	0.25	0.25	2.07	21.1	**0.00**			
11/2/2008	2.41	56.3	2.16	28.8	0.25	0.25	2.16	28.8	**0.00**			
11/7/2008	2.49	67	2.24	36.2	0.25	0.25	2.24	36.2	**0.00**			
11/14/2008	3.15	201	2.9	148	0.25	0.25	2.90	148	**0.00**			
11/21/2008	2.59	82.4	2.34	47.1	0.25	0.25	2.34	47.1	**0.00**			
11/28/2008	2.61	85.8	2.36	49.6	0.25	0.25	2.36	49.6	**0.00**			
12/7/2008	2.78	119	2.54	74.3	0.24	0.25	2.53	72.8	**2.02**			
12/10/2008	3.03	174	2.79	122	0.24	0.25	2.78	119	**2.46**			
								Average	**0.41**			
Sample 21	**32A120 (from rating 12)**											
2/28/2009	3.44	274	3.4	264	0.04	0.05	3.39	261	**1.14**	**0.013**	**0.03**	

Date	Log St.	Log St. Q	Obs St.	Obs St. Q	Diff Ft.	Avg.Diff Ft.	Log-Avg. Diff Ft.	Log-Avg. Diff Ft. Q	% Diff	Diff Ft. STDEV	Range	Notes
3/2/2009	3.55	304	3.51	293	0.04	0.05	3.50	290	**1.02**			
3/3/2009	3.83	386	3.78	371	0.05	0.05	3.78	371	**0.00**			
3/13/2009	3.16	204	3.09	187	0.07	0.05	3.11	192	**2.67**			
3/20/2009	3.67	339	3.61	321	0.06	0.05	3.62	324	**0.93**			
3/27/2009	3.96	427	3.92	414	0.04	0.05	3.91	411	**0.72**			
								Average	**1.08**			
Sample 22	**32A120 (from rating 13)**											
6/12/2009	3.03	129	2.96	116	0.07	0.07	2.96	116	**0.00**	**0.005**	**0.01**	
6/19/2009	2.81	87	2.74	75.7	0.07	0.07	2.74	75.7	**0.00**			
6/25/2009	2.47	41	2.4	34.3	0.07	0.07	2.40	34.3	**0.00**			
7/2/2009	2.14	15	2.06	10.7	0.08	0.07	2.07	11.2	**4.67**			
7/13/2009	2.33	28.4	2.26	22.8	0.07	0.07	2.26	22.8	**0.00**			
7/22/2009	2.11	13.4	2.04	9.7	0.07	0.07	2.04	9.7	**0.00**			
7/31/2009	2.08	11.7	2	8.01	0.08	0.07	2.01	8.41	**4.99**			
8/14/2009	2.22	20	2.14	15	0.08	0.07	2.15	15.5	**3.33**			
								Average	**1.62**			
Sample 23	**32A120 (from rating 13)**											
8/28/2009	2.16	16.1	2.08	11.7	0.08	0.07	2.09	12.2	**4.27**	**0.012**	**0.02**	
9/11/2009	2.23	20.7	2.17	16.7	0.06	0.07	2.16	16.1	**3.59**			
9/25/2009	2.22	20	2.14	15	0.08	0.07	2.15	15.5	**3.33**			
								Average	**3.73**			
Sample 24	**03B075 (from rating 1)**											
3/23/2006	3.79	74.9	3.8	76.2	-0.01	-0.01	3.80	76.2	**0.00**	**0.012**	**0.03**	
4/19/2006	4.17	127	4.17	127	0	-0.01	4.18	128	**0.79**			
6/7/2006	3.83	80.1	3.86	84.1	-0.03	-0.01	3.84	81.4	**3.21**			
8/9/2006	3.22	22.4	3.22	22.4	0	-0.01	3.23	23	**2.68**			
9/20/2006	3.18	20.1	3.19	20.6	-0.01	-0.01	3.19	20.6	**0.00**			
								Average	**1.34**			

Date	Log St.	Log St. Q	Obs St.	Obs St. Q	Diff Ft.	Avg.Diff Ft.	Log-Avg. Diff Ft.	Log-Avg. Diff Ft. Q	% Diff	Diff Ft. STDEV	Range	Notes
Sample 25	**03B075 (from rating 2)**											
2/21/2007	5.32	370	5.34	375	-0.02	-0.02	5.34	375	**0.00**	**0.006**	**0.01**	
4/11/2007	4.12	119	4.14	122	-0.02	-0.02	4.14	122	**0.00**			
4/30/2007	4.21	133	4.24	138	-0.03	-0.02	4.23	136	**1.45**			
								Average	**0.48**			
Sample 26	**35L050 (from rating 13)**											
1/13/2009	5.29	18.2	5.23	16	0.06	0.08	5.21	15	**6.25**	**0.014**	**0.04**	
1/29/2009	4.91	2.57	4.84	1.34	0.07	0.08	4.83	1.21	**9.70**			
2/6/2009	4.94	3.26	4.84	1.34	0.1	0.08	4.86	1.62	**20.90**			
2/19/2009	4.85		4.76		0.09							Q values below rating (less than value shown)
2/24/2009	4.93	3.01	4.86	1.62	0.07	0.08	4.85	1.47	**9.26**			
3/9/2009	5.12	10.4	5.04	6.49	0.08	0.08	5.04	6.49	**0.00**			
3/23/2009	5.23	16	5.16	12.4	0.07	0.08	5.15	11.9	**4.03**			
								Average	**8.36**			
Sample 27	**35L050 (from rating 11)**											
4/24/2009	5.11	12	5.02	9.52	0.09	0.09	5.02	9.52	**0.00**	**0.010**	**0.03**	
5/10/2009	5.03	9.78	4.95	7.9	0.08	0.09	4.94	7.68	**2.78**			
5/13/2009	5.01	9.27	4.91	7.06	0.1	0.09	4.92	7.26	**2.83**			
6/5/2009	4.8	5.09	4.71	3.65	0.09	0.09	4.71	3.65	**0.00**			
6/17/2009	4.71	3.65	4.64	2.73	0.07	0.09	4.62	2.5	**8.42**			
6/23/2009	4.74	4.1	4.65	2.85	0.09	0.09	4.65	2.85	**0.00**			
								Average	**2.34**			
Sample 28	**35L050 (from ratings 11, 12 and 13)**											
7/20/2009	4.58	2.09	4.5	1.35	0.08	0.08	4.50	1.35	**0.00**	**0.005**	**0.01**	Rating 11
8/10/2009	4.87	3.06	4.78	1.35	0.09	0.08	4.79	1.49	**10.37**			Rating 12
8/22/2009	4.92	3.6	4.84	1.9	0.08	0.08	4.84	1.9	**0.00**			Phased Period*
8/30/2009	4.95	4.39	4.87	2.42	0.08	0.08	4.87	2.42	**0.00**			Phased Period*

Date	Log St.	Log St. Q	Obs St.	Obs St. Q	Diff Ft.	Avg.Diff Ft.	Log-Avg. Diff Ft.	Log-Avg. Diff Ft. Q	% Diff	Diff Ft. STDEV	Range	Notes
9/14/2009	4.93	3.85	4.85	2.06	0.08	0.08	4.85	2.06	**0.00**			Phased Period*
9/22/2009	4.93	3.01	4.84	1.34	0.09	0.08	4.85	1.47	**9.70**			Rating 13
9/30/2009	4.93	3.85	4.84	1.9	0.09	0.08	4.85	2.06	**8.42**			Phased Period*
								Average	**4.07**			
Sample 29	**17C075 (from ratings 3 and 4)**											
12/21/2007	1.61	15.1	1.65	16	-0.04	-0.04	1.65	16.6	**3.75**	**0.009**	**0.02**	Rating 3
12/30/2007	1.45	9.95	1.48	10.8	-0.03	-0.04	1.49	11.1	**2.78**			Rating 3
1/4/2008	2.5	69.9	2.55	72.7	-0.05	-0.04	2.54	72.2	**0.69**			Rating 3
1/11/2008	1.9	28.5	1.95	31.4	-0.05	-0.04	1.94	30.8	**1.91**			Rating 4
1/17/2008	1.7	18.4	1.75	21	-0.05	-0.04	1.74	20.4	**2.86**			Rating 4
								Average	**2.40**			
Sample 30	**17C075 (from rating 4)**											
6/6/2008	1.61	14.3	1.62	14.7	-0.01	-0.02	1.63	15.1	**2.72**	**0.008**	**0.02**	
6/15/2008	1.51	10.4	1.53	11.2	-0.02	-0.02	1.53	11.2	**0.00**			
6/23/2008	1.4	4.24	1.42	5.07	-0.02	-0.02	1.42	5.07	**0.00**			
6/27/2008	1.36	2.94	1.38	3.54	-0.02	-0.02	1.38	3.54	**0.00**			
7/2/2008	1.33	1.99	1.36	2.94	-0.03	-0.02	1.35	2.59	**11.90**			
7/14/2008	1.3	1.33	1.31	1.53	-0.01	-0.02	1.32	1.74	**13.73**			
7/18/2008	1.28	1	1.31	1.53	-0.03	-0.02	1.30	1.33	**13.07**			
7/26/2008	1.27	0.87	1.3	1.33	-0.03	-0.02	1.29	1.16	**12.78**			
8/3/2008	1.28	1	1.3	1.33	-0.02	-0.02	1.30	1.33	**0.00**			
8/11/2008	1.28	1	1.3	1.33	-0.02	-0.02	1.30	1.33	**0.00**			
8/23/2008	1.26	1.64	1.29	2.17	-0.03	-0.02	1.28	2	**7.83**			Phased Period*
9/1/2008	1.25		1.28		-0.03							Phased Period*/ Q values below rating (less than value shown)
9/7/2008	1.22		1.25		-0.03							Phased Period*/ Q values below rating (less than value shown)
								Average	**5.64**			
Sample 31	**17C075 (from rating 4)**											

Date	Log St.	Log St. Q	Obs St.	Obs St. Q	Diff Ft.	Avg.Diff Ft.	Log-Avg. Diff Ft.	Log-Avg. Diff Ft. Q	% Diff	Diff Ft. STDEV	Range	Notes
2/2/2008	1.38	3.54	1.42	5.07	-0.04	-0.05	1.43	5.53	**9.07**	**0.005**	**0.01**	
2/7/2008	1.48	8.53	1.52	10.8	-0.04	-0.05	1.53	11.2	**3.70**			
2/15/2008	1.57	12.7	1.62	14.7	-0.05	-0.05	1.62	14.7	**0.00**			
2/21/2008	1.49	9.28	1.54	11.6	-0.05	-0.05	1.54	11.6	**0.00**			
2/27/2008	1.45	6.59	1.5	10.1	-0.05	-0.05	1.50	10.1	**0.00**			
								Average	**2.56**			

*Discharge values for observations during phased periods are averages of separate discharges at same stage between two phased ratings.

Stable Drift Analysis

Average Standard Deviation = 0.013
Percent Average Diff obs st. Q = 2.4
Stdev of Percent Average Diff obs st. Q= 1.9
Average Range= 0.03

Log St. = logged stage at time of PGI observation.
Obs. St. = observed stage at PGI.
Obs. St. Q = discharge as read from active rating table corresponding to observed gage height value at PGI.
Diff. Ft. = difference between the logged stage value and the PGI observation.
Avg. Diff Ft. = average of the set of differences in feet.
Log-Avg. Diff Ft. = stage of difference between logged stage value and average difference in feet
Log-Avg. Diff Ft. Q = discharge as read from appropriate rating table corresponding to Log-Avg. Diff Ft. value
% Diff = difference in discharge expressed in percent between Obs. St. Q and Log-Avg. Diff Ft. Q
Average % Diff = average of the set of % differences in discharges between Obs. St. Q and Log-Avg. Diff Ft. Q
Diff Ft. STDEV = standard deviation of differences between logged stage value and PGI observation. Threshold value for stable drift consideration is 0.15 ft.
Range = difference between greatest Diff Ft. value and least Threshold value for stable drift consideration is 0.03 ft.

Samples with average % diff met the established criteria for standard deviation and range of diff Ft.