QUALITY ASSURANCE PROJECT PLAN
LUMMI NATION CONTINUOUS TEMPERATURE MONITORING PROJECT

Version 2.0

Water Resources Division
Natural Resources Department
Lummi Indian Business Council

May 2020

Lummi Nation Continuous Temperature Monitoring Quality Assurance Project Plan Approval (A1):

Name and Title	Signature	Date
Leroy Deardorff Lummi Nation Natural Resources Department Deputy Director	Leroy Deardorff	7/2/2020
Kara Kuhlman Lummi Nation Project Manager and Quality Assurance Manager LIBC Water Resources Manager		7/2/2020
Jamie L. Mattson Lummi Nation Water Quality Monitoring Quality Assurance Officer LIBC Water Resources Specialist II/Planner	Jamie L. Mattson	7/5/2020
Hanna Winter Lummi Nation Water Quality Monitoring Program Coordinator LIBC Water Resources Specialist II	Hanna Winter	6/30/2020
~~**Westley Foster**~~- **Kristy Fry** USEPA Project Manager EPA Tribal Coordinator	KRISTY FRY Digitally signed by KRISTY FRY Date: 2020.07.06 08:41:40 -07'00'	
Donald M. Brown USEPA Quality Assurance Officer	KARIN FEDDERSEN-LETHE Digitally signed by KARIN FEDDERSEN-LETHE Date: 2020.07.06 08:44:45 -07'00'	

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DISTRIBUTION LIST (A3)

Merle Jefferson, Lummi Nation Natural Resources Director
(360) 312-2328; merlej@lummi-nsn.gov

Leroy Deardorff, Lummi Nation Natural Resources Deputy Director
(360) 312-2318; leroyd@lummi-nsn.gov

Kara Kuhlman, Lummi Nation Water Resources Manager
(360) 312-2128; karak@lummi-nsn.gov

Jamie L. Mattson, Lummi Nation Water Resources Specialist II/Planner
(360) 312-2313; jamiem@lummi-nsn.gov

Hanna Winter, Lummi Nation Water Resources Specialist II
(360) 312-2312; hannaw@lummi-nsn.gov

Shamania James, Water Resources Technician II
(360) 384-7101; shamaniaj@lummi-nsn.gov

Jeffrey Solomon, Natural Resources Technician II
(360) 312-2128; jeffreys@lummi-nsn.gov

Craig Dolphin, Database Manager
(360) 312-2304; craigd@lummi-nsn.gov

Westley Foster, EPA Tribal Coordinator
(206) 553-1604; foster.westley@epa.gov

Donald M. Brown, EPA Region10 Quality Assurance Officer
(206) 553-0717; brown.donaldm@epa.gov

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REVISION RECORD

<table>
<tr><th>Approval #</th><th>Responsible Person</th><th>Date</th></tr>
<tr><td>1.0</td><td>Jeremy Freimund</td><td>September 2015</td></tr>
<tr><th colspan="2">Description of Change</th><th>Location of Change</th></tr>
<tr><td colspan="2">Initial Approval and Release of Version 1.0</td><td>N/A</td></tr>
<tr><th>Approval #</th><th>Responsible Person</th><th>Date</th></tr>
<tr><td>2.0</td><td>Kara Kuhlman</td><td>May 2020</td></tr>
<tr><th colspan="2">Description of Change</th><th>Location of Change</th></tr>
<tr><td colspan="2">Moved distribution list to before TOC</td><td>Page i</td></tr>
<tr><td colspan="2">Revisions to document to match other WQM Program QAPPs, removing specific details included in QMP, and adding reference to the QMP as appropriate</td><td>Changed: Section 1, 1.3, 2.2, 5.1, 6.1, 10.1
Added: Revision Record, Signature Page, Section 1.1., 1.2, 3.1, 3.2, 5.2, 5.3, 8
Removed: Section 2.3, 3.3, 4.1, 5.3, Figure 2.1, Table 2.1, 2.2</td></tr>
<tr><td colspan="2">Changed “Program” to “Project” and “the Program” to “the CTM Project”</td><td>Throughout</td></tr>
<tr><td colspan="2">Updated job titles and responsibilities</td><td>Section 1.2, 10.1, 10.2</td></tr>
<tr><td colspan="2">Changed Water Quality Assessment Report frequency from annual to every other year</td><td>Section 3.2, 10.2</td></tr>
<tr><td colspan="2">Changed procedure for triannual accuracy checks:
• Changed frequency from quarterly to three times per year (triannual)</td><td>Sections 3.2, 4.1, 6.4.8, 6.6, 7, 7.2, 7.3, 7.7, 9, 9.1, 9.1
Tables 7.2, 9.2
Appendix A, Appendix B</td></tr>
<tr><td colspan="2">• Accuracy check no longer conducted in the field</td><td>Section 3.2, 4.1, 4.3, 6.6, 7.3, 7.3.2,
Table 9.2
Removed: Section 7.3.4</td></tr>
<tr><td colspan="2">• Only reference thermometer used, no reference temperature probe option, including error of reference temperature probe as part of total error</td><td>Section 3.2, 4.3, 6.6, 7.3, 7.3.1, 7.3.5, 7.5
Table 7.1, 7.2, 9.2
Removed: Section 7.3.2</td></tr>
</table>

Approval #	Responsible Person	Date
2.0	Kara Kuhlman	May 2020
Description of Change, Continued		**Location of Change**
• Removed “laboratory” from description of annual two-point accuracy check because both accuracy checks are now conducted in the laboratory and clarified that this procedure used as annual check and pre-deployment check		Section 3.2, 4.1, 6.6, 7.2 Removed: Section 7.4
• Correction and clarification of accuracy check steps, including changing measurement interval for accuracy checks and time needed for logger equilibration in the lab.		Changed: Section 6.6, 7.3 Added section titles and updated: Section 7.2.1, 7.2.2, 7.2.3, 7.2.4, 7.2.5, 7.3.1, 7.3.3, 7.3.4, 7.3.5
• Updated options for data adjustment during accuracy checks to include change in reference temperature during triannual accuracy check		Section 7.3.4, Table 7.2
Changed CTM Project sites. Removed SW051 and added SR005 due to deployment challenges at SW051. SW008 now represents lowest extent of Lummi River, with SR005 as mid-point monitoring site.		Table 3.1, 3.2; Figure 3.1
Added section on logger specifications		Section 3.5
Changed acceptance criteria for pre-deployment and annual two-point accuracy check from 0.2 to 0.5°C. Overall project acceptance criterion remains unchanged at 0.5°C.		Section 4.1, 4.3, 7.2.5, 7.5
Added acceptance criterion for precision of continuous temperature loggers of a difference between the maximum and minimum logger temperature measurement collected during annual 2-point accuracy check to ≤0.2°C.		Section 4.2, 6.6, 7.2.2, 7.2.3, 7.2.5, 7.3.5, Table 7.1
Corrected data management and validation process to reflect that the Datalogger Database only contains final data. Rejected or excluded data are not uploaded to the database. Qualifiers are marked in source datasheets and suspect data are not uploaded to the database. Only final data are used or summary statistics and reporting.		Section 9.2, 9.5, 9.7.2, 9.7.3
Corrected minimum resolution (readability) from 0.2 to 0.1°C and range from 0-25 to 0-35°C		Section 4.7
Updated location of electronic file storage, file types, and file naming conventions		Section 5.3, 6.5 Added Section 9.1, Table 9.1
Removed continuous data transmittal to STORET via WQX because these databases do not support continuous data. CTM Project data are not transmitted to STORET at this time.		Section 5.2, 9, 10.1

Approval #	Responsible Person	Date
2.0	Kara Kuhlman	May 2020
Description of Change, Continued		**Location of Change**
Changed title from "Logger Deployment and Data Collection (B2 Sampling Methods)" to "Sampling Methods (B2)" and added introductory paragraph.		Section 6
Changed frequency of cross-section surveys from twice per year to once per year with rotating trimester.		Section 6.2.2
Added threshold guideline of 0.5°C difference in maximum-minimum variability to trigger a full cross-section survey. Added guidance for site selection to have temperature that differs no more than 0.5°C from the cross-section mean.		Section 6.2.2
Moved Appendix C figure to Section 6.3.1 Protective Housing		Figure 6.2 Deleted Appendix C
Added details to Logger Set-Up, including specifics on timing of temperature measurement logging interval and file naming		Section 6.3.3
Moved Appendix D figures to the relevant section under Section 6.4 Deployment Strategy		Figures 6.3-6.6 Deleted Appendix D
Added Section 6.4.6 PVC Housing as a deployment strategy		Section 6.4.6, Figure 6.7
Added detailed instructions for using spherical densiometer for canopy cover measurements		Section 6.4.8, Figure 6.8
Added section regarding site maintenance		Added Section 6.4.9
Moved Appendix A and Appendix B to a stand-alone document: Standard Operating Procedures for HOBO Temp Pro V2 continuous temperature loggers (LWRD 2020). Changed reference to SOP from Appendix B to LWRD 2020 throughout.		Removed Appendix A and Appendix B
Combined Section 7.8 Corrective Action to Section 7.5 Acceptance Criteria and Corrective Actions. Updated Table 7.2. Moved Section 7.7 Requirements of the Reference Thermometer to Section 7.6.		Sections 7.5-7.8, Table 7.2
Updated Equipment Maintenance: removed "and Calibration" from title, added persons responsible, and cleaning of loggers.		Section 7.7
Updated references		Section 11
Updated datasheets and decision trees and re-numbered appendices		Appendix A (previously Appendix E) and Appendix B (previously Appendix F)

SIGNATURE PAGE

Document: Continuous Temperature Monitoring Project QAPP

Version 2.0

The following technical staff have read this manual. A copy of this page will be distributed to the employee training record file.

Signature	**Date**
Name (printed)	**Title**

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1. DOCUMENT AND PROJECT ORGANIZATION

1.1 Document Organization

This document is organized following Environmental Protection Agency (EPA) Requirements for Quality Assurance Project Plans (EPA 2001, reissued 2006) with the companion document Guidance for Quality Assurance Project Plans (EPA 2002). Where a letter and number follow a section title (e.g., Distribution List [A3]), they indicate the corresponding section in the EPA Requirements for Quality Assurance Project Plans.

The Lummi Nation Continuous Temperature Monitoring (CTM) Project is a component of the Lummi Nation Water Quality Monitoring (WQM) Program. The overall quality system for the WQM Program is outlined in a Quality Management Plan (QMP), which serves as the umbrella document for the WQM Program and its component projects. Individual Quality Assurance Project Plans (QAPPs) have been developed for each individual project within the WQM Program. The individual projects include the following:

- Ambient Surface Water Quality Monitoring Project
- Ambient Groundwater Quality and Quantity Monitoring Project
- Continuous Temperature Monitoring Project (this document)
- First Flush Monitoring Project
- Department of Health Support (National Shellfish Sanitation Program) Project
- Nutrient, Metal, and Hydrocarbon Monitoring Project
- Continuous Water Level Monitoring Project
- Lummi Peninsula Groundwater Settlement Agreement Compliance Monitoring Project
- ZAPS Technologies LiquID Station Continuous Water Quality Monitoring Study

In addition, Standard Operating Procedures (SOPs) have been developed for each instrument used or parameter measured.

1.2 Project Organization (A4)

The Continuous Temperature Monitoring (CTM) Project is implemented and administered through the Lummi Water Resources Division (LWRD) of the Lummi Natural Resources Department (LNR), contained under the Lummi Indian Business Council (LIBC). An organizational chart of the individuals participating in the CTM Project is provided in the QMP. A complete and detailed discussion of the structure of the WQM Program, including organization charts identifying the components of all projects part of the WQM Program and individuals participating in the WQM Program are provided in the QMP (LWRD 2019c).

In summary, the Water Resources Specialist II is the primary staff person responsible for CTM Project coordination, including maintaining the official, approved QAPP. The Water Resources Specialist II, Water Resources Technician II, and Natural Resources Technician II are responsible for implementing the CTM Project. The Water Resources Specialist II supervises the Water Resources Technician II and Natural Resources Technician II and provides approval and oversight of the CTM Project. The Water Resources Manager supervises the Water Resources Specialist II, is responsible for distribution of the final approved QAPP, and evaluates compliance with project goals and makes recommendations to the LNR Director and Deputy Director, who make decisions based upon data collected as part of the CTM Project. The Database Manager created and maintains the Datalogger Database and is the primary staff member responsible for database development, training, and documentation.

1.3 Special Training Requirements and Certification (A8)

Details on the roles, contact information, position requirements, and qualifications held by the individuals responsible for managing and implementing the CTM Project are listed in detail in the QMP. The QMP also includes details on the required and recommended training and certification for all staff involved in the WQM Program. Supervisors and the Water Resources Manager are responsible for ensuring staff are qualified and trained.

2. PROBLEM DEFINITION AND BACKGROUND (A5)

2.1 Project Summary

The Continuous Temperature Monitoring (CTM) Project will provide continuous temperature data from ten surface water sites on the Reservation to determine whether these waters meet the Water Quality Standards for Surface Waters of the Lummi Indian Reservation (17 LAR 07).

Water temperature will be measured every 30 minutes at 10 sites, and rolling 7-day averages of the daily maximum water temperature (7DADM) for freshwater sites and 1-day maximum water temperature for marine water sites will be calculated. These temperatures will be compared with ambient water quality temperature criteria for the designated water quality class for the particular system monitored. The results of this project will advise regulatory actions, restoration efforts, and Total Maximum Daily Load development, as determined by the Water Resources Manager, Natural Resources Director, and Natural Resources Deputy Director.

2.2 Project Context

The CTM Project is implemented by the LWRD, which has the overall goal of protecting treaty rights to water of sufficient quantity and quality to (a) support the purposes of the Reservation as a permanent economically viable homeland for the Lummi People and (b) to support a sustainable harvestable surplus of salmon and shellfish to maintain a moderate living standard.

The CTM Project is a component of the Lummi Nation Water Quality Monitoring Program (WQM Program). The goals of the WQM Program are threefold:

1. To establish the baseline conditions of surface and ground waters on and flowing onto the Reservation;
2. To use this information to evaluate regulatory compliance of waters flowing onto the Reservation; and
3. To support the development and implementation of a water quality regulatory program (e.g., Lummi Code of Laws Title 17, Lummi Nation Water Quality Standards) on the Reservation.

The WQM Program is an important element of the Comprehensive Water Resources Management Program (CWRMP). Additional details on project context and related projects are provided in the QMP. Two important milestones in the CWRMP development were the January 2004 adoption of the Lummi Nation Water Resources Protection Code (Title 17 of the Lummi Code of Laws) and the August 2007 adoption of the *Water Quality Standards for Surface Waters of the Reservation* (Lummi Nation Water Quality Standards; 17 LAR 07), which the EPA approved in September 2008. The Lummi Nation Water Quality Standards detail four surface water classes and their characteristic uses, and provide numeric water quality criteria for, among others, water temperature. Additional details on the Lummi Nation Water Quality

Standards are provided in the QMP. Applicable criteria and action limits are also provided in the QMP.

2.3 Water Temperature

There are numerous threats to Lummi Nation Waters.[1] These threats are described in detail in the Lummi Nation Nonpoint Source Management Plan (LWRD 2002), the Lummi Nation Nonpoint Source Pollution Management Plan: 2015-2020 (LWRD 2015b) and other documents developed as part of the Lummi Nation CWRMP (LWRD 1997, 1998, 2000, and 2001) and associated updates (LWRD 2011a, 2011b, and 2015a). The Continuous Temperature Monitoring Project is focused on monitoring surface water temperatures for waters flowing onto the Reservation and within the Nooksack River.

Increases in water temperature can affect water quality and biotic communities, particularly salmonids, in several ways. Temperature is one of the most important parameters influencing salmonid biology. Because salmonids are poikilotherms, as are most aquatic organisms, their internal temperature and metabolism are determined by the ambient water temperature. Water temperature influences incubation and early fry development, growth and feeding rates, smoltification, swimming speed, and the timing of life history events such as upstream migration, spawning, freshwater rearing, and seaward migration. Thermal stress can result from temperatures that are too warm, resulting in death or reduced fitness that impairs processes such as growth, spawning, smoltification, or swimming speed (McCullough et al. 2001). Thermal stress can also block migration, create disease problems, and alter competitive dominance (Carter 2005). Higher temperatures also reduce the amount of dissolved oxygen available to aquatic organisms, potentially resulting in respiratory stress. In addition, elevated water temperature also increases the solubility of most metals and chemicals and reduces their adsorption to sediment particles, increasing pollutant concentrations within the water column.

Twenty (20) waterbody segments of the Nooksack River mainstem, including the forks of the Nooksack River, are listed as impaired by high water temperature on the Washington State 303(d) list (Ecology 2014), and six segments are considered waters of concern. In the Nooksack River watershed, 57 waterbody segments are listed as temperature impaired (Ecology 2014). In Reservation waters monitored by LWRD in 2016 and 2017, 100% (five of five) of the freshwater and 100% (three of three) of the marine sites exceeded the temperature water quality criteria for Class AA Extraordinary waters (LWRD 2019a). A previous report suggested low flow and/or shallow water that had flowed over sun-warmed sediments or tideflats were likely causes of water quality violations (LWRD 2001). In addition, the likely primary causes of increased water temperatures in the Nooksack River and on the Reservation in general are reduced shading, altered channel structure (e.g., wide, shallow streams), and loss of contributions from groundwater base flow, all three of which are due to agricultural practices, forestry, and land development (LWRD 2001).

[1] Pursuant to 17.09.010 of the Lummi Code of Laws, Lummi Nation Water includes all fresh and marine waters that originate or flow in, into, or through the Reservation, or that are stored on the Reservation, whether found on the surface of the earth or underground, and all Lummi Nation tribal reserved water rights.

2.4 Lummi Nation Surface Water Quality Standards

The Lummi Nation Surface Water Quality Standards detail four surface water classes (AA Extraordinary, A Excellent, B Good, and Lake Class) and their characteristic uses, and provides water quality criteria for a variety of parameters for each class. EPA approved these water quality standards in September 2008. Surface water quality criteria for temperature is measured as a seven-day average of the daily maximum value (7DADM) for freshwater and a one-day maximum for marine water. Class AA Extraordinary waters provide the greatest number of characteristic uses, including salmonid migration, juvenile rearing, spawning, egg incubation, and fry emergence, and therefore have the most stringent water temperature criteria. Class AA Extraordinary freshwater temperature may not exceed a 7DADM of 16.0°C or, for summertime spawning, a 7DADM of 13.0°C. Marine waters considered Class AA Extraordinary may not exceed a 1-day maximum temperature of 13.0°C. Class A Excellent waters support salmonid migration and juvenile rearing, but not critical uses such as salmonid spawning, egg incubation and fry emergence. Class A Excellent freshwaters may not exceed a 7DADM temperature of 17.5°C, while Class A marine waters may not exceed a 1-day maximum temperature of 16.0°C. Class B Good waters also support salmonid migration and juvenile rearing, but do not support clam, oyster, mussel, crustacean, or other shellfish harvesting. Class B Good freshwaters may not exceed a 7DADM temperature of 17.5°C and marine waters may not exceed a 1-day maximum temperature of 19.0°C. See Table 2.1 for details on the characteristic uses and temperature criteria for each surface water class.

Table 2.1 Lummi Nation Surface Water Quality Standards Characteristic Uses and Temperature Criteria (17 LAR 07)

Class AA Extraordinary	Class A Excellent	Class B Good	Lake Class
Characteristic Uses			
(A) Water supply (domestic, commercial, municipal, industrial, agricultural). (B) Stock watering. (C) Fish and shellfish: Salmonid migration, juvenile rearing, spawning, egg incubation, fry emergence, and harvesting. Other fish migration, juvenile rearing, spawning, egg incubation, fry emergence, and harvesting. Clam, oyster, and mussel rearing, spawning, and harvesting. Crustaceans and other shellfish (crabs, shrimp, crayfish, scallops, geoduck, etc.) rearing, spawning, and harvesting. (D) Wildlife habitat. (E) Recreation (extraordinary primary contact, primary contact, sport fishing, boating, canoeing, and aesthetic enjoyment). (F) Commerce and navigation. (G) Tribal Cultural.	(A) Water supply (domestic, commercial, municipal, industrial, agricultural). (B) Stock watering. (C) Fish and shellfish: Salmonid migration, juvenile rearing, and harvesting. Other fish migration, juvenile rearing, spawning, egg incubation, fry emergence, and harvesting. Clam, oyster, and mussel rearing, spawning, and harvesting. Crustaceans and other shellfish (crabs, shrimp, crayfish, scallops, geoduck, etc.) rearing, spawning, and harvesting. (D) Wildlife habitat. (E) Recreation (primary contact, sport fishing, boating, canoeing, and aesthetic enjoyment). (F) Commerce and navigation. (G) Tribal Cultural.	(A) Water supply (industrial, agricultural). (B) Stock watering. (C) Fish and shellfish: Salmonid migration, juvenile rearing, and harvesting. Other fish migration, juvenile rearing, spawning, egg incubation, fry emergence, and harvesting. Clam, oyster, and mussel rearing, and spawning. Crustaceans and other shellfish (crabs, shrimp, crayfish, scallops, geoduck, etc.) rearing, and spawning. (D) Wildlife habitat. (E) Recreation (secondary contact, sport fishing, boating, canoeing, and aesthetic enjoyment). (F) Commerce and navigation. (G) Tribal Cultural.	(A) Water supply (domestic, commercial, municipal, industrial, agricultural). (B) Stock watering. (C) Fish and shellfish: Salmonid migration, juvenile rearing, spawning, egg incubation, fry emergence, and harvesting. Other fish migration, juvenile rearing, spawning, egg incubation, fry emergence, and harvesting. Clam and mussel rearing and spawning. Crayfish rearing and spawning. (D) Wildlife habitat. (E) Recreation (extraordinary primary contact, primary contact, sport fishing, boating, canoeing, and aesthetic enjoyment). (F) Commerce and navigation. (G) Tribal Cultural.
Freshwater Temperature			
Shall not exceed a 7-day average of the daily maximum value (7DADM) temperature of 16.0°C. For summertime spawning, temperature shall not exceed a 7DADM temperature of 13.0°C.	Shall not exceed a 7DADM temperature of 17.5°C.	Shall not exceed a 7DADM temperature of 17.5°C.	No measurable increase from natural conditions.
Marine Water Temperature			
Shall not exceed a 1-day maximum temperature of 13.0°C	Shall not exceed a 1-day maximum temperature of 16.0°C	Shall not exceed a 1-day maximum temperature of 19.0°C	N/A

2.5 Project Justification

Prior to 2009, the Ambient Surface Water Quality Monitoring Project only involved collection of single measurements of water temperature at each site during a sampling run; typically once per month per site. Because the water quality standards are expressed as the 7-day average of the daily maximum (7DADM) water temperature for freshwater sites and as the 1-day maximum water temperature for marine water sites, continuous temperature monitoring is needed to accurately evaluate compliance of waters flowing onto and within the Reservation with the Lummi Nation Water Quality Standards.

Between 2009 and 2013, continuous temperature monitoring loggers were deployed at ten surface water monitoring sites. The collected data were to be used for informational purposes only as there were no approved quality assurance/quality control (QA/QC) procedures in place during that time. It is noted that the continuous temperature loggers were deployed and operated pursuant to manufacturer instructions but a formal QAPP was not developed due to work load and time constraints. In 2015, Version 1.0 of this QAPP was approved and provided the QA/QC procedures needed to verify the quality of the data collected under this project in order to use data collected for evaluation of trends, impairment, and compliance with water quality criteria.

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3. PROJECT DESCRIPTION (A6) AND EXPERIMENTAL DESIGN (B1)

The Continuous Temperature Monitoring (CTM) Project was launched in 2009, when continuous temperature loggers were deployed at ten monitoring sites.

3.1 Project Goals

The initial QAPP for the project was developed and approved in 2015. The overall objective of the CTM Project is to achieve the overall LWRD mission and the WQM Program goals (Section 2.2). Specifically, the objectives of the CTM Project are:

- To establish the baseline conditions of surface waters on and flowing onto the Reservation;
- To use this information to evaluate regulatory compliance of waters flowing onto and through the Reservation; and
- To support the development and implementation of a water quality regulatory program (e.g., Lummi Code of Laws Title 17, Water Quality Standards) on the Reservation.

3.2 Project Description

Specifically, the CTM Project will provide data to determine whether surface waters on the Reservation meet the ambient water temperature criteria for the assigned water quality class for that particular system. Seven Class AA freshwater and three Class AA marine water sites were selected for continuous temperature monitoring under this project. See Table 3.1 and Figure 3.1 for details on the selected monitoring sites. One of the sites will also be used as a continuous air temperature monitoring site (site SW011) to provide a measure of air temperature on the Reservation concurrent with water temperature measurements. Air temperature is monitored to provide a comparison with water temperature measurements, and to assist in identification of data errors such as may occur when a water temperature logger becomes dewatered.

The continuous temperature loggers will be deployed at the ten monitoring sites listed in Table 3.1 following the procedures outlined in Section 6 of this QAPP. The loggers will be programmed to record a temperature measurement every 30 minutes. The temperature data will be downloaded from each logger three times per year: in January, May, and September. Daily running seven-day averages of the daily maximum temperature (7DADM) will be calculated for each freshwater site and 1-day maximum temperature will be calculated for each marine water site. These will be compared to the temperature criteria for each designated class, as listed in the Lummi Nation Surface Water Quality Standards. The temperature data and comparison to the Surface Water Quality Standards will be included in the Water Quality Assessment Report, which will be transmitted every-other year to the EPA by March 31 of the following calendar year after the two-year reporting period upon approval by the Water Resources Manager and the LNR Deputy Director.

Quality assurance and quality control (QA/QC) procedures include manufacturer calibration and logger replacement as specified in the equipment Standard Operating Procedures (SOP), annual two-point accuracy checks, and triannual accuracy checks with a reference thermometer. Details of the QA/QC procedures are provided in Section 7.

Table 3.1 Continuous Temperature Monitoring Sites

Sample Site ID	Sample Site Name	Water Class Designation
SW003	Jordan Creek at North Red River Road	Class AA Freshwater
SW008	Lummi River at Hillaire Road Bridge	Class AA Marine Water
SW009	Lummi River at Slater Road	Class AA Freshwater
SW011	Jordan Creek at Slater Road	Class AA Freshwater
SW012	Schell Creek at Slater Road	Class AA Freshwater
SW015	Smuggler Slough at Lummi Shore Drive	Class AA Freshwater
SR005	Lummi River at Haxton Way	Class AA Freshwater
SW053	North Lummi River Distributary Mouth	Class AA Marine Water
SW059	Smuggler Slough at Kwina Road	Class AA Marine Water
SW118	Nooksack River at Marine Drive Bridge	Class AA Freshwater

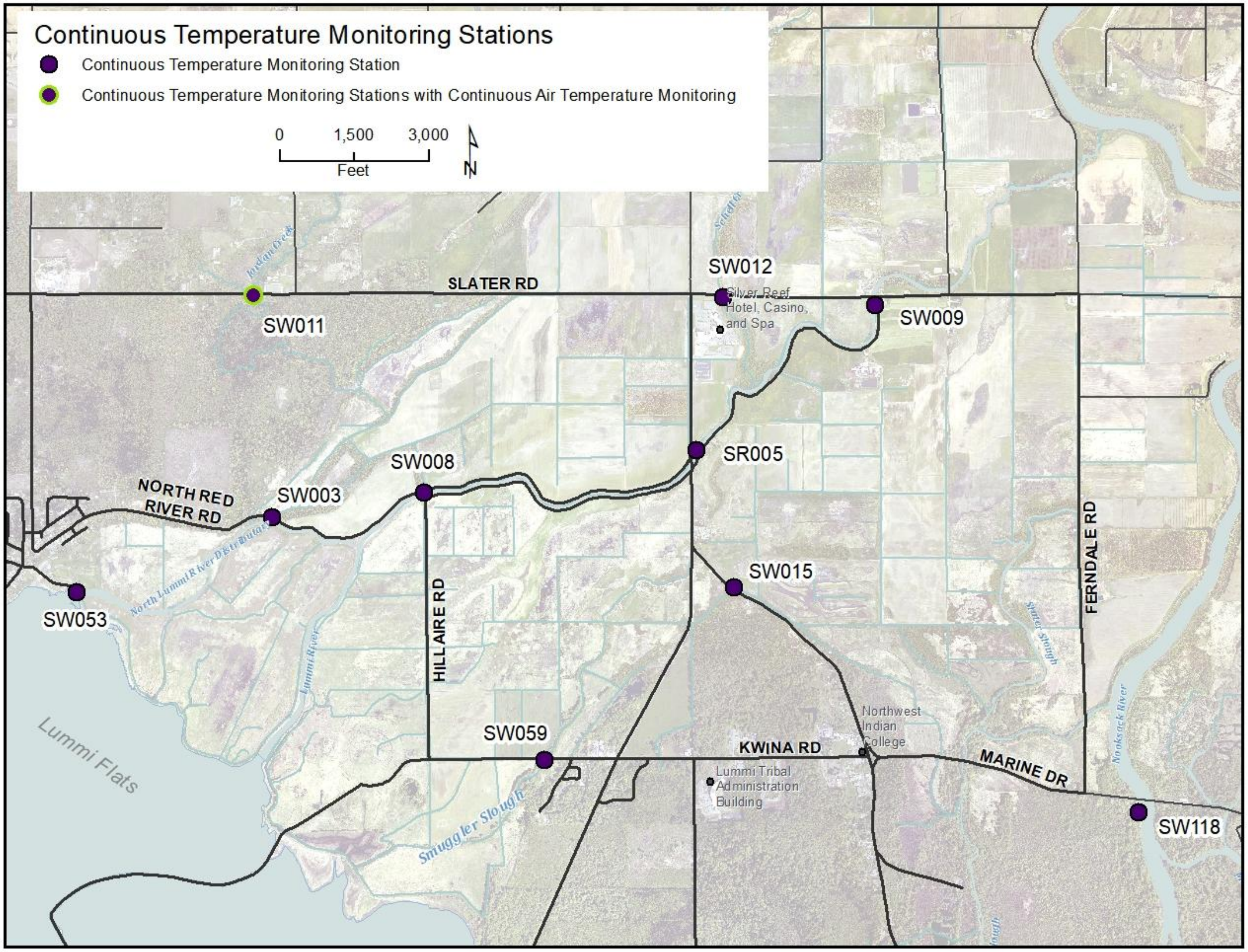

Figure 3.1 Location of Continuous Temperature Monitoring Sites

3.3 Design Justification

The monitoring sites were selected to represent four systems: the North Lummi River Distributary (SW003, SW011, SW053), the Lummi River (SR005, SW008, SW009, SW012), Smuggler Slough (SW015, SW059) and the Nooksack River (SW118). These sites are routinely sampled monthly (or more frequently for SW118) as part of the Ambient Surface Water Quality Monitoring Project. Site SW011 was selected for continuous air temperature monitoring to provide air temperature measurements for comparison with the water temperature measurements, and to assist in identification of logger dewatering events. Site SW011 is relatively secluded and is forested, resulting in cooler air temperatures due to shading from solar radiation.

Table 3.2 presents further details on the rationale for selecting sites for continuous temperature monitoring.

Table 3.2 Rationale of Site Selection for Continuous Temperature Monitoring Project

Site ID	Description	Rationale for Continuous Temperature Monitoring
Jordan Creek/North Lummi River Distributary		
SW053	North Lummi River Distributary Mouth	Site SW053 characterizes the North Lummi River Distributary as it discharges into Lummi Bay.
SW003	Jordan Creek at North Red River Road	Jordan Creek is a freshwater tributary to the North Lummi River Distributary. Site SW003 characterizes Jordan Creek upstream of the confluence of Jordan Creek and the North Lummi River Distributary main stem.
SW011	Jordan Creek at Slater Road	Jordan Creek is a freshwater tributary to the North Lummi River Distributary. Site SW011 characterizes Jordan Creek as it enters the Reservation. This site was also selected for continuous air temperature monitoring due to its secluded location and forest cover.
Lummi River		
SW008	Lummi River at Hillaire Road Bridge	The Lummi River at site SW008 is considered a marine water site because it is inundated with marine water during high tides. Due to the logistical complexity of deploying a continuous temperature logger at the mouth of the Lummi River, this site represents the tidally-influenced downstream end of the Lummi River as it enters the marine receiving waters.
SR005	Lummi River at Haxton Way Pedestrian Bridge	The Lummi River at site SR005 represents the river below the confluence of three freshwater drainages that enter the Reservation at its northern boundary along Slater Road.

Site ID	Description	Rationale for Continuous Temperature Monitoring
SW009	Lummi River at Slater Road	Site SW009 characterizes the Lummi River as it crosses onto the Reservation.
Lummi River, continued		
SW012	Schell Creek at Slater Road	Schell Creek is a freshwater tributary to the Lummi River. Site SW012 characterizes the tributary as it crosses onto the Reservation.
Smuggler Slough		
SW059	Smuggler Slough at Kwina Road	Smuggler Slough flows into Lummi Bay at tide gates near the mouth of the Lummi River. This drainage is 100% contained within the Reservation. SW059 is a marine site located within Area B of the Blockhouse Site for the Lummi Nation Wetland and Habitat Mitigation Bank.
SW015	Smuggler Slough at Lummi Shore Road	Smuggler Slough flows into Lummi Bay at tide gates near the mouth of the Lummi River. This drainage is 100% contained within the Reservation. SW015 is a freshwater site.
Nooksack River		
SW118	Nooksack River at Marine Drive Bridge	The Nooksack River drains 786 square miles of Whatcom and Skagit Counties into Bellingham Bay. Site SW118 characterizes the river upstream of its delta.

3.4 Alternate Sites

In the event that continuous temperature data are available for any of the selected sites listed above from another source,[2] the continuous temperature loggers from those sites are redeployed to alternate, additional locations. Duplication of data collection is avoided to conserve resources and maximize the dataset of continuous temperature data. In addition, in the event that deployment of continuous temperature loggers is not possible because of logistical reasons, alternate locations may be used. The alternate site will be selected based on representativeness, water quality concerns, and feasibility of deployment and site access.

Alternate sites include (Figure 3.2):

- Portage Island (e.g., SW027)

[2] Continuous temperature monitoring is conducted by other divisions within the LNR. The Restoration Division occasionally conducts continuous temperature monitoring at several sites within Smugglers Slough and connected waterways. If continuous temperature sensors are deployed by the Restoration Division, LWRD staff responsible for implementing this QAPP will work with Restoration staff to ensure that continuous temperature data collected by Restoration Division staff can be used in addition to data collected under this QAPP. If continuous temperature loggers are deployed by the Restoration Division in a location listed as a continuous temperature monitoring site in this QAPP, LWRD staff will not deploy a continuous temperature logger at that location to avoid duplication of data collection efforts. An alternate site will be selected under these circumstances.

- Sandy Point Marina (e.g., SW001, SW019)
- Seaponds Creek (i.e., SW029)
- Seaponds Aquaculture Facility (e.g., DOH044, DOH045)
- Nooksack River Delta (e.g., fish point boat launch near Howard's and Native American Seafoods)

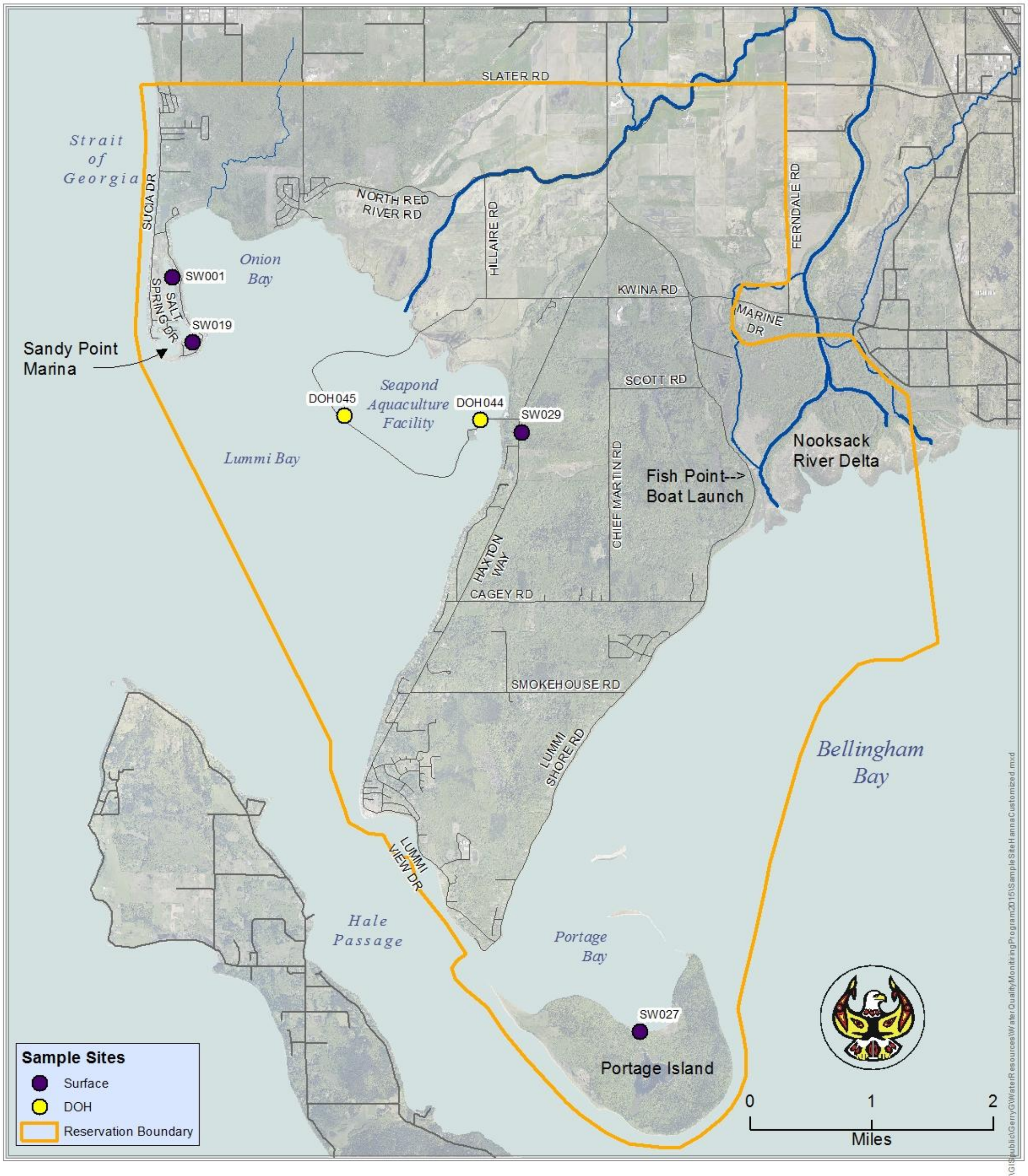

Figure 3.2 Alternate continuous temperature monitoring sites

3.5 Logger Specifications

Continuous temperature loggers used for the CTM Project must meet the listed project quality objectives and acceptance criteria (Section 4). Loggers must have a minimum range of 0-35°C, sensitivity or resolution of 0.1°C, and accuracy of ±0.5°C. Loggers must be able to be deployed in the field without maintenance for 3 months at a time and able to record temperature measurements at 10-20 second intervals as well as 30 minute intervals. Logger software must support ability to export data into Excel formats (.csv or .xls/.xlsx). Currently, HOBO Water Temp Pro v2 continuous temperature loggers are used for the CTM Project and a SOP has been developed for these loggers (LWRD 2020). Other loggers that may be used include other HOBO temperature loggers, HOBO U20L water level and temperature loggers, HOBO pendant, or HOBO TidbiT temperature loggers or any continuous temperature logger that meets the project quality objectives and acceptance criteria. Standard Operating Procedures (SOPs) for alternate loggers are developed prior to use as part of the CTM Project.

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4. QUALITY OBJECTIVES AND CRITERIA (A7)

The overall performance standard for the Continuous Temperature Monitoring Project is the collection of high-quality continuous temperature data sufficient to meet project goals. Data must be of sufficient quality (i.e., known precision, accuracy, bias, traceability, completeness, and representativeness) to support decisions based upon the water quality data. Quality control activities are designed to indicate data quality prior to logger deployment or after data download and prompt corrective actions at that time, if necessary. In addition, quality control activities provide information necessary to assess and quantify data quality and comparability for data analysis.

The CTM Project is ongoing and is not designed to prove or disprove a specific hypothesis. The data are used to assist in identifying and addressing actual and potential impairments of water quality and for evaluation of water temperature trends against regulatory criteria. Quality control activities are in place to ensure the reliability and usefulness of the temperature data for evaluation of trends, impairment, and compliance with water quality criteria.

Running 7DADM and 1-day maximum temperatures will be systematically calculated for each freshwater and marine site, respectively, using tools included in the Datalogger Database following data screening and identification of data errors (see Section 9.3) and data correction, as needed (see Section 9.4).

4.1 Measurement Performance/Acceptance Criteria

Quality assurance/quality control (QA/QC) procedures include calibration by the manufacturer, a pre-deployment accuracy check, triannual accuracy checks, and an annual 2-point accuracy check (see Section 7). The continuous temperature logger standard operating procedure (SOP) lists QA/QC procedures and maintenance requirements specific to the temperature loggers (e.g., LWRD 2020).

The overall acceptance criterion for the CTM Project is ±0.5°C. If a pre-deployment or annual laboratory accuracy check reveals the difference between the reference temperature and the logger temperature is greater than ±0.5°C, corrective actions will be taken or the instrument will be returned to the manufacturer for recalibration or replacement (see Sections 7.5). If a triannual accuracy check reveals greater than ±0.5°C difference between the reference temperature and measured logger temperature, corrective actions will be taken (see Section 7.5) and data will be corrected or data will be excluded (see Section 9.4).

4.2 Precision

Precision will be calculated from measurements during accuracy checks by collecting several temperature measurements within a short period of time. Range (minimum-maximum), difference between the maximum and minimum measurements, and standard deviation will be calculated to determine precision during annual two-point accuracy checks. Precision must meet the manufacturer-stated precision of the instrument, if available, or the difference between the minimum and maximum measurements must remain less than or equal to 0.2°C. Although ideal for determining data precision, deployment of two loggers per site is not practical due to budget limitations.

Manufacturer-stated resolution and precision (if available) for the continuous temperature logger is listed in the SOP for the logger.

4.3 Accuracy and Bias

Accuracy of CTM Project temperature measurements is no greater than ±0.5°C. The actual accuracy of the continuous temperature loggers is specified by the manufacturer (see SOP; e.g., LWRD 2020). The continuous temperature loggers will be calibrated by the manufacturer and accuracy will be verified annually in the lab at representative temperatures (0 and 20°C) and three times per year at ambient temperatures. A NIST-traceable thermometer will be used for all accuracy checks (see Section 7.6 for specific requirements of the reference thermometer).

4.4 Representativeness

Temperature loggers will be deployed in locations representative of the aquatic system to be monitored. The following considerations will be taken into account when choosing a representative location for temperature logger installation:

- Low flow or low tide conditions: the logger will need to be installed in a location where it will remain under water during all flow and tide conditions.
- Potential for burial in sediment: the logger will need to be installed in a location where it will remain above the stream bottom during all flow and tide conditions. High flows can cause loggers to be covered with sediment.
- Thermal stratification (vertical or horizontal) and mixing zones: the logger will need to be installed in a location without thermal stratification.
- Where have samples been collected historically? If all else is equal, the logger will be placed in a location as near as practical to the location where samples are collected as part of the Ambient Surface Water Quality Monitoring Project.

Variation is determined using a stream cross-section survey, as needed (Section 6.2.2).

4.5 Comparability

Temperature data will be collected at ten selected sites. Upon data validation and verification, year to year temperature data from this project can be used to describe temperature trends at each site.

Continuous temperature monitoring will be conducted at sites that are a part of the Ambient Surface Water Quality Monitoring Project. Water quality parameters (temperature, pH, salinity, conductivity, dissolved oxygen and bacteria [fecal coliform, *Escherichia coli*, *Enterococcus*]) are measured monthly from a representative location at these sites. Continuous temperature monitoring data can also be compared to the discrete water temperature data collected at these sites.

Continuous temperature data collected by other LNR divisions (e.g., Restoration Division) may be used to provide supplemental temperature data for additional sites on the Reservation. If the temperature data were collected following an approved QAPP, these data may be used in addition to the data collected under this QAPP to determine whether these waters meet the Surface Water Quality Standards.

The U.S. Geological Survey (USGS) maintains a gaging station on the Nooksack River at Ferndale (USGS 12213100) with temperature data available as daily minimum, maximum and average. Continuous temperature data collected at site SW118 (Nooksack River at Marine Drive Bridge) may be compared to the Nooksack River gage at Ferndale to describe the general temperature conditions in the Nooksack River.

4.6 Completeness

The goal of the CTM Project is to collect temperature data from each of the ten selected sites every 30 minutes year-round. Data gaps may affect future analysis of baseline conditions and comparison to regulatory criteria, but do not immediately compromise the integrity of the monitoring project because the monitoring is not attempting to answer a specific hypothesis. Data gaps are addressed on a case-by-case basis. Short data gaps will occur due to removal of the loggers for download and QA/QC activities. Missing data may be due to staff turnover, resource constraints, equipment failure, corrective actions, and logistical problems. Corrective actions are undertaken to remedy conditions that create missing data to prevent data gaps in the future (Section 7.5).

4.7 Range/Sensitivity

The sensitivity of the temperature data collected and range of temperatures that can be measured will depend on the equipment selected. The goal is to maintain a minimum resolution of 0.1°C within the typical range of temperatures for surface waters on the Reservation (0-35°C).

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5. DOCUMENTS AND RECORDS (A9)

5.1 Quality Assurance Project Plan Distribution

The Water Resources Specialist II is responsible for ensuring that the people listed on the Distribution List for this QAPP have the most current version of the QAPP. Records are maintained by the Water Resources Specialist II documenting substantial and minor version changes. The Water Resources Manager is responsible for the distribution of minor change letters and revised QAPPs. Details on documenting QAPP revisions, including version number conventions, are included in the QMP (LWRD 2019c).

5.2 Data Report Package

Results of the CTM Project will be included in the Water Quality Assessment Report, which summarizes the results of the WQM Program implemented by the LWRD every two years. The reports include analysis of water quality data for the two-year reporting period as well as for the period of record. Daily 7DADM will be reported for freshwater sites and 1-day maximum temperature will be reported for marine sites. The report is provided to the EPA Project Officer every-other year by March 31 of the year after the two-year reporting period, following approval by the Water Resources Manager and the Natural Resources Deputy Director.

5.3 Documentation and Storage

The QMP provides detailed requirements for project document storage, including field datasheets and electronic data.

In summary, the Water Resources Specialist II is responsible for maintaining and storing all documents and records associated with the CTM Project. All continuous data are stored in the Datalogger Database, which is saved on LIBC servers that are backed up regularly, and in back up Excel spreadsheets also saved on LIBC servers.

All run details, manufacturer calibrations, completed QA/QC procedures (i.e., accuracy checks), site visit observations, notes on issues or concerns, corrective actions, and outcomes are recorded on field datasheets in electronic format or are recorded on paper and scanned and saved as PDFs. All paper records (e.g., deployment and retrieval datasheets and cross-section survey datasheets) are stored by the Water Resources Specialist II in the LWRD office. All electronic records are saved in the Datalogger folder on the Z:\ drive and/or the H:\ drive (Digital Archives), which is regularly backed up (Section 9.1).

Recorded information includes: logger and reference thermometer identification information, deployment location, measurement times, logger temperature readings, reference thermometer readings, and calculations. All field notes will be recorded, including: names of persons performing the work, site identification, site description (including a sketch or photos, if applicable), logger deployment notes, logger deployment location, time of deployment (note daylight savings time or standard time), time of data download, physical description of logger (including any fouling observed), quality control activities, and corrective actions. Datasheets are included in Appendix A. Datasheets are saved as Excel templates and cells containing calculations are protected to prevent accidental changes. File storage location and file naming conventions are listed in Section 9.1.

6. SAMPLING METHODS (B2)

Sampling methods (B2) are described below. No physical water quality samples are collected as part of the CTM Project (B3). This section describes safety during data collection activities, equipment required for sample runs, deployment location selection and characterization, logger preparation, logger deployment, data download, and the sampling method sequence.

6.1 Safety

All field work is conducted by teams of two or more. All procedures listed in the *Lummi Water Resources Division Health and Safety Plan* (LWRD 2019b) are followed while conducting laboratory and field work outlined in this QAPP. Safety is not addressed in detail in this document; however, no water quality measurement is worth risking injury or death. To ensure that hazards are identified and addressed, field personnel must maintain a general awareness of hazards and possess the ability to respond appropriately. Field personnel must be aware of the environment, use common sense and training, and not exceed their abilities or limits. Field personnel always wear life jackets (when performing boat-based sampling), carry a cell phone and car charger, and inform their supervisor of planned field work, including the time of departure, the time of scheduled return, and the general location of field work. A float plan is required when using the boat for sample collection.

6.2 Deployment Location

6.2.1 *Representative Location*

Loggers will be deployed in a representative location at the monitoring site. A representative location should have the following attributes:

1. Well mixed – the site should not be thermally stratified at any time of year.
    a. Determine whether thermal stratification occurs during different seasons and flows. Horizontal and vertical stratification is checked once per year. See Section 6.2.2 for details.
    b. Consider effect of groundwater, storm water, and tributary contributions into the stream.
    c. Do not deploy loggers in stagnant water, eddies, backwater, reverse flows, areas of faster than normal flow, or any other features that could affect water temperature.
2. Accessible – the site should be safely accessible at all times of year.
3. Sufficient depth – the logger needs to be underwater at all times, including times of very low flow. The site will be selected to ensure that the logger is covered by 12 inches of water at all times. Some sites may have less than 12 inches of water at low flows; in these situations, the deepest location will be selected or a new site will be selected.

4. Avoid sedimentation – the logger needs to be above the stream bed at all times. High flow events can cause sediment buildup at the stream bottom, leading to burial of the logger in sediment. This can bias temperature readings, and should be avoided by placing the logger in a location at least 6 inches above the stream bottom, if practical.
5. Secure –
    a. The site should be in a location that is not readily obvious to passersby, due to the potential for vandalism or people who are curious and may remove the logger from the water, inadvertently exposing it to air and compromising the quality of the data collected by the logger.
    b. The site should be in a location where the logger can be securely attached to the stream bottom or bank.

6.2.2 *Cross-Section Survey*

All CTM Project sites are checked for vertical and horizontal variability to ensure that the continuous temperature loggers are deployed in a representative location. Vertical and horizontal variability is checked once annually prior to re-deployment of loggers, with the month during which the temperature variability check is conducted rotating by year so that each trimester is assessed once every three years (e.g., September in year 1, January in year 2, and May in year 3). Temperature is measured at five horizontal locations on a cross-section of the stream or river at the logger deployment site. At each horizontal location, temperature is measured at a minimum of two depths. If the difference between the minimum and maximum temperature is greater than 0.5°C, horizontal or vertical variability in the temperature readings is present and a formal cross-section stream survey is required.

Cross-section stream surveys using the Equal Width Increment method are conducted at sites where horizontal and/or vertical temperature variability is identified during twice-annual checks. Stream width is measured using a metal measuring tape (or other non-stretching measuring device), and divided into a minimum of 5 horizontal increments. Depth is measured in the mid-point of each horizontal increment.

The size of the vertical increment is selected depending on stream depth. The size of the vertical increment should be the same for each horizontal increment, but the number of vertical increments in each horizontal increment will depend on the depth. A minimum of two vertical increments are required. Temperature is measured in the top 12 inches of the mid-point of each horizontal increment for the first (surface) vertical increment and in the middle of each of the subsequent vertical increments (see Figure 6.1). The mean, range (minimum-maximum), and standard deviation are calculated to determine representativeness of logger location in comparison to the full stream cross-section.

If the stream does not have sufficient depth, no vertical increments are needed; only horizontal representativeness and variability can be determined. Calculate mean and standard deviation to determine representativeness of logger location in comparison to the full stream cross-section. Survey information will be logged into an Excel datasheet that will automatically calculate mean and standard deviation (see Appendix A).

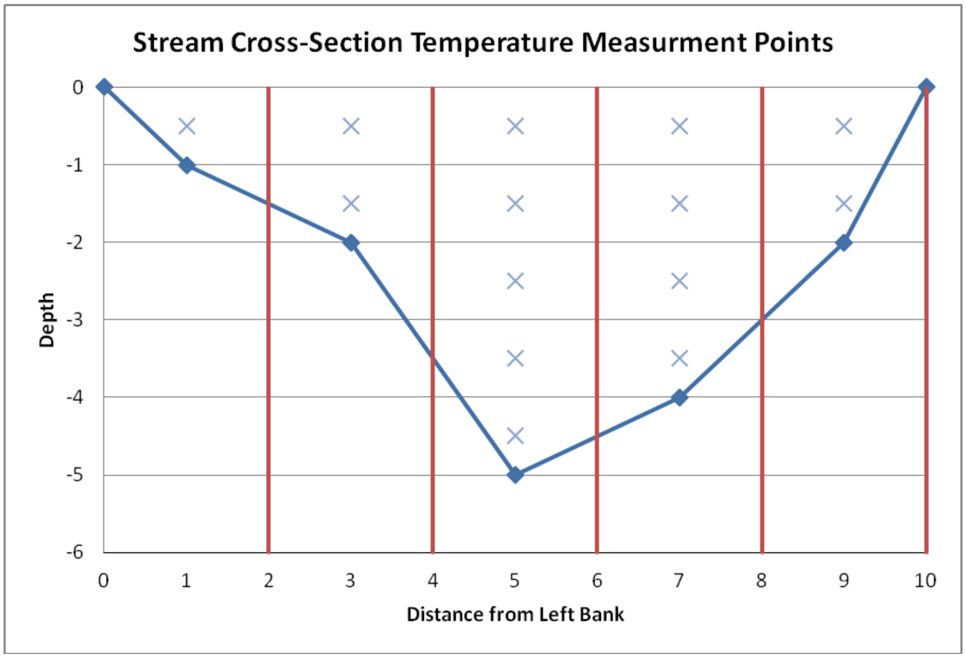


Figure 6.1 Schematic of temperature measuring points in cross-section stream survey. Temperature readings collected at evenly spaced horizontal and vertical increments to determine representativeness of logger deployment location.

The mean, range, and standard deviation of the cross-section are used for site characterization and to help guide selection of the deployment location. If the temperature at the deployment location differs by more than 0.5°C from the cross-section mean during flowing conditions, additional cross-sections in the vicinity are evaluated for a more representative location. If a more representative location cannot be found (i.e., where the temperature at the deployment location differs by less than 0.5°C from the cross-section mean), the logger is deployed at the most representative location (i.e., where the temperature is the closest to the cross-section mean) that meets the other deployment location criteria (Section 6.2.1) and this is noted during reporting of the continuous temperature monitoring results. Sites that are salinity stratified and/or have seasonal low flow that result in spatial temporal variability are not necessarily reasons to discontinue continuous temperature monitoring at a site. The continuous temperature data in a portion of the cross-section remains useful for site characterization and compliance determination, but the variability should be acknowledged and considered when evaluating and interpreting the dataset. For example, a deeper, cooler deployment location may provide monitoring of cold-water refuges for salmon or other cold-water species as well as limit overestimation of periods of noncompliance due to placement in a cooler portion of the cross-section.

6.3 Logger Preparation for Deployment

6.3.1 *Protective Housing*

All loggers are fitted with a protective housing to reduce solar radiation and damage. Loggers are placed inside a short length of PVC pipe with ¼-inch vent holes (Figure 6.2). The holes allow water to flow through the protective housing while the PVC pipe protects the logger from loose gravel, rocks and other debris that may damage the logger and shades it from solar radiation. To secure the protective housing to the logger, pass a wire, cable, or ziptie through the vent holes and through the logger's mounting hole. To secure a logger to rebar, block, or buoy, a wire, cable, or ziptie can be threaded through the vent holes on the protective housing.

The protective housing can include an engraved, aluminum tag with LWRD's contact information. In the event that the logger and protective housing are separated from the cable or rebar and are found, the logger can be returned to the LWRD.

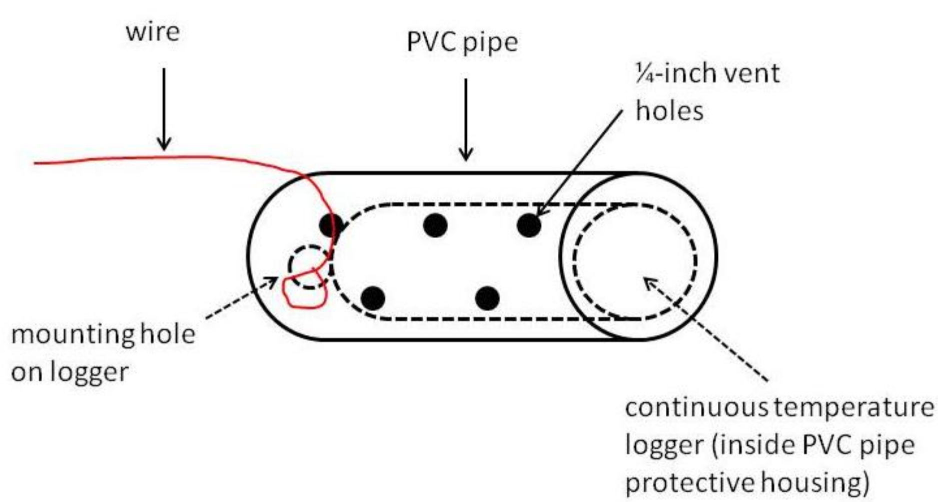


Figure 6.2 Schematic of continuous temperature logger in protective housing.

6.3.2 *Pre-Deployment QA/QC*

Accuracy check procedures are required prior to logger deployment (Section 7.2).

6.3.3 *Logger Set-Up*

The loggers are programmed to log a temperature measurement every 30 minutes, on the hour and 30 minutes past the hour. The programmed file name should indicate the site name at which the logger is deployed, the type of programming (QA activity or temperature deployment), and the date measurements began. For field deployment, the file name should be saved as the site ID, underscore, "Temp", underscore, date temperature measurements began in year, month, day format (YYYYMMDD): for example SW011_Temp_20200315 for temperature deployment at site SW011 beginning March 15, 2020. See logger SOP for details (LWRD 2020).

6.4 Deployment Strategy

Several logger deployment options are considered for each site and the most appropriate and feasible option selected. This means that the same deployment method may not be used at all sites.

6.4.1 *Rebar*

Bent rebar (approximately 4 feet in length, with one longer leg than the other) is driven into the stream bottom deep enough to stay in place during high flows. The logger, encased in its protective housing, is attached to the rebar by cable ties or wire with the enclosed end of the protective housing facing upstream or up toward the water surface (Figure 6.3).

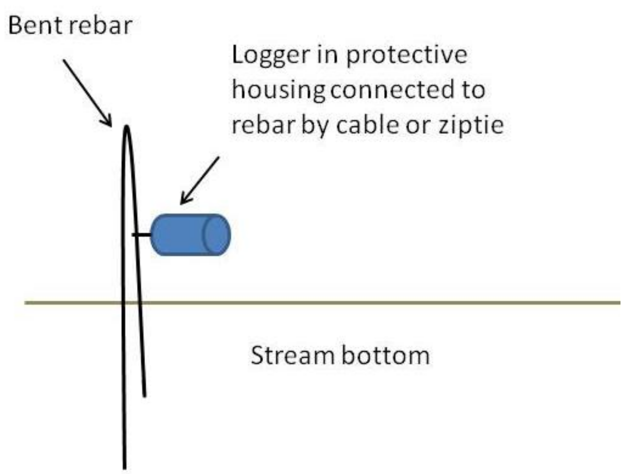


Figure 6.3 Schematic for rebar deployment technique. The logger can also be attached to the rebar upright (not shown).

6.4.2 *Cable*

Heavy-duty (e.g., 120-lb tensile strength) cable is attached to rebar or stable instream structures such as large rocks/boulders, roots, woody debris, or a cinder block placed in the stream. Alternatively, the cable can be attached to a stable structure on the stream bank and extended into the stream. The logger, encased in its protective housing, is attached to the cable using cable ties or wire at two points with the enclosed end of the protective housing facing upstream.

6.4.3 *Cinder Block*

The logger, encased in its protective housing, is attached to the top or side of a cinder block using zip ties, cable, or wire. The logger is placed with the enclosed end of the protective housing facing upstream or up toward the water surface (Figure 6.4). The cinder block is connected to a stable structure on the stream bank for additional security for sites with periodic high flows.

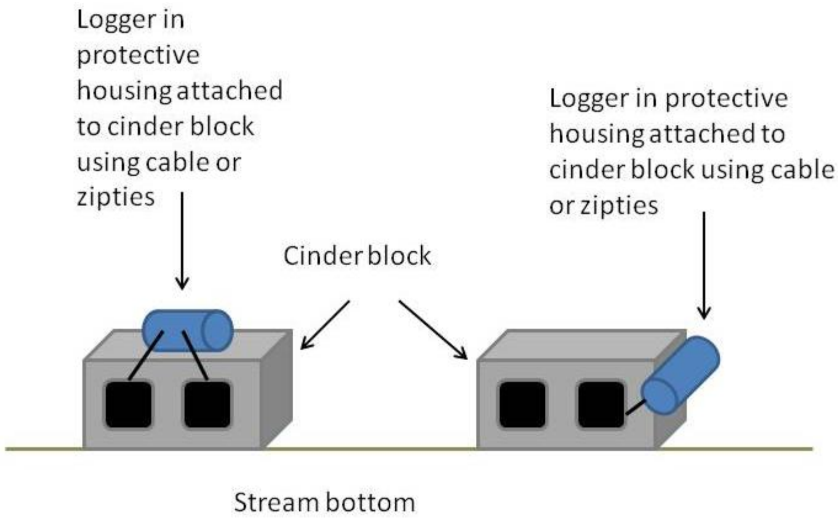


Figure 6.4 Schematic of cinder block deployment technique. The logger is attached to the top or side of the cinder block, which can be secured to a stable structure on the stream bank.

6.4.4 *Custom Block*

The logger is attached to custom-built block if there is the potential for the logger to be buried in sediment. The locations must have sufficient water depth at low flows to avoid dewatering the logger with this deployment method as the logger will sit higher in the water column. The logger is attached to two eyelets in the block using cable ties or wire with the enclosed end of the protective housing facing upstream (Figure 6.5). The block is placed in the stream and a cable is attached to a third eyelet, which is attached to rebar or a stable structure instream or on the stream bank.

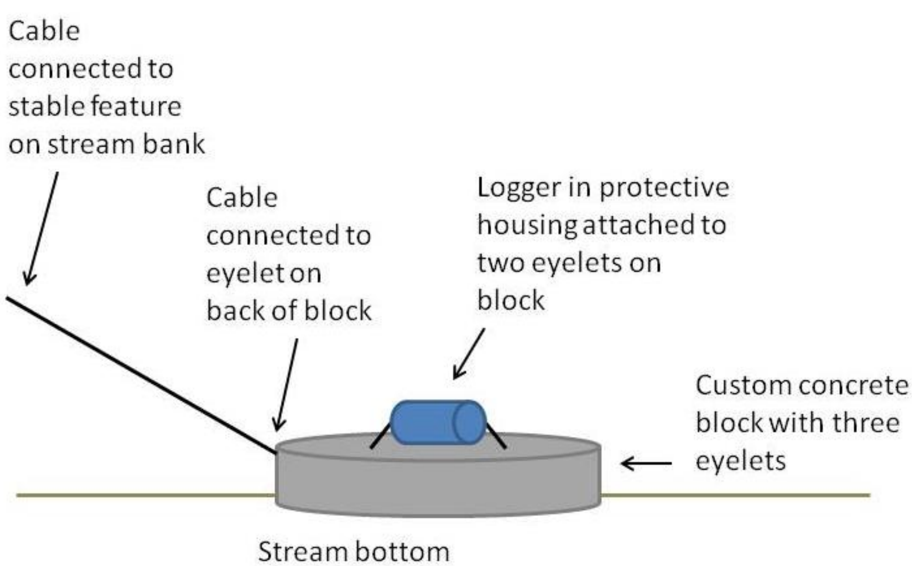


Figure 6.5 Schematic of the custom-built concrete block deployment technique. An eyelet on the block is attached to a stable feature on the stream bank with cable and the logger is connected to the block at two eyelets.

6.4.5 *Weight and Buoy*

At sites with sufficient water depth at low flows and considerable sedimentation along the stream bed, a weight and buoy combination can be used to keep the logger low in the water column but above the stream bottom. A large brick or cinder block is attached to a cable that is secured to a stable structure on the stream bank. A second cable (approximately 2-3 feet in length) from the brick or cinder block is secured to a foam buoy. The brick or cinder block and buoy must be appropriately sized so that the buoy does not pull the brick into the water column from the stream bottom. The logger, encased in its protective housing, is attached to the buoy or to the buoy line with the enclosed end of the protective housing facing up toward the water surface (Figure 6.6).

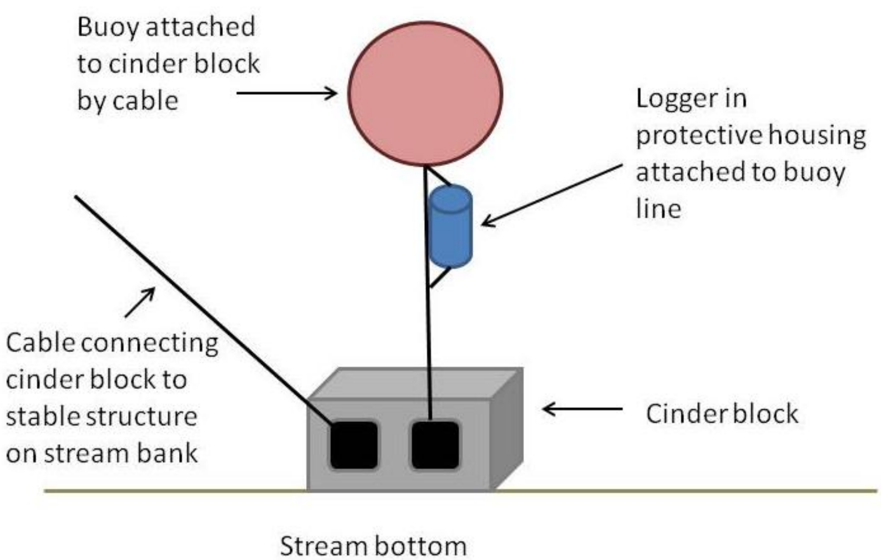


Figure 6.6 Schematic of weight and buoy deployment technique. A cinder block or other heavy item used as a weight is secured to a stable structure on the stream bank using a cable. A buoy is attached to the cinder block by cable (approximately 2-3 feet long) and the logger is attached to the buoy.

6.4.6 *PVC Housing*

A length of PVC tube is strapped to rebar or fence posts driven into the soil or sediment on either side of the PVC tube so that the PVC tube extends from a safe location on shore down the stream bank, at an angle, into the deepest part of the stream channel so that the end of the tube is submerged during all flow conditions (Figure 6.7). At least two anchoring points are used; more are needed for longer lengths of PVC tubing (e.g., greater than 8 feet). The lower (instream) end of the PVC tube is fitted with a bolt to prevent the logger from sliding through the end and ¼-inch vent holes, similar to the protective housing, are drilled into the bottom six inches of the PVC tube. At the top (on-shore) end of the PVC tube, a cable attached to the logger is anchored so that the logger can be pulled out easily. A cap and lock can be fitted to the on-shore end of the PVC tube especially if there are concerns about tampering at the deployment location. A thinner (1/2-inch diameter) PVC tube can be used to push the logger to the instream end of the PVC tube.

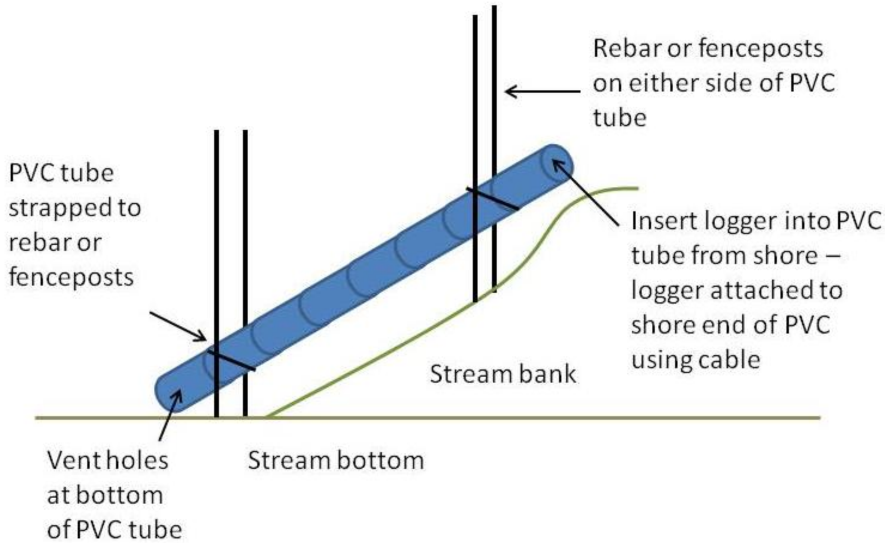


Figure 6.7 Schematic of instream PVC tube technique. PVC tube is anchored to stream bottom and stream bank using rebar or fenceposts. Logger is placed in tube so that it rests at the bottom (instream) end of the PVC tube and is attached to the shore end of the PVC tube for easy removal.

6.4.7 *Air Temperature*

The air temperature logger is also encased in a protective PVC housing to protect it from debris and solar radiation. The logger is attached to a tree within 10 feet of the stream bank as near as possible to the water temperature logger deployed at the same location. The logger is attached to the tree using cable ties or wire at two points. The selected site should be accessible by field crew, but not readily visible to passersby. A shady site is selected for air temperature logger deployment and the logger attached in a way that reduces solar radiation effects on the temperature measurements.

6.4.8 *Canopy Cover*

Canopy cover at the deployment site is measured with a spherical densiometer using the Strickler (1959) modification (Figure 6.8). The spherical densitometer is modified by covering a portion of the 24 grid squares to create 17 measuring points. This modification removes the problem of overlap in canopy cover readings when four readings (in each of four cardinal directions) are taken from a static location and resultant frequent overestimate of canopy cover.

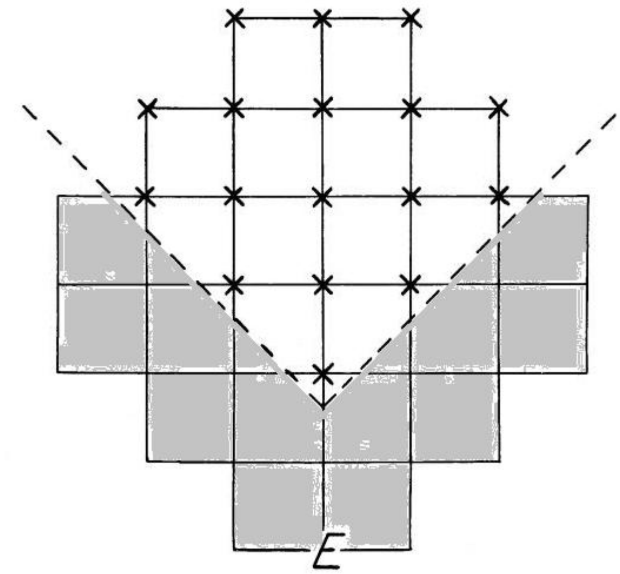
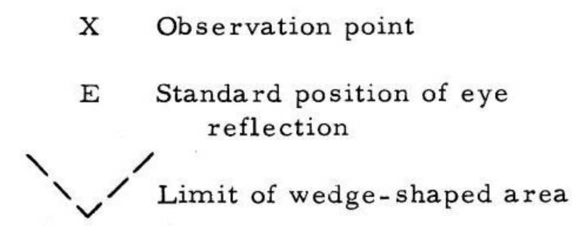


Figure 6.8 Densiometer modification from Strickler 1959. The portions of grid squares in gray are blocked using electrical tape. The 17 measuring points are marked with an X at the corners of each square.



Canopy cover is determined when temperature loggers are initially deployed and each time they are redeployed following triannual accuracy checks. Densiometer readings are taken as near to the continuous temperature logger deployment location as feasible. Four readings are taken at a static location facing north, east, south, and west. Facing each cardinal direction, a canopy cover measurement is taken using the following procedures:

1. Hold densiometer 12-18 inches away from body at elbow height with the lid of the densiometer open and the lid and mirrored wedge facing outward.
2. Position the densiometer so that the bubble at the lower right hand corner is in the middle of the circle (i.e., level).
3. Observe the area of the mirrored surface obscured by canopy vegetation. Count the number of dots on the mirror obscured by canopy vegetation.
    - Each corner of the exposed grid squares is a measuring point (Figure 6.8)
    - There are 17 measuring points. The reading should be between 0 (no points covered) and 17 (all points covered).
4. Record the number of points covered on the deployment datasheet.
5. Repeat steps 1-4 for each cardinal direction (north, east, south, and west).
6. To calculate total canopy cover, sum the four readings, multiply by 1.5, and apply correction factor due to modified method.
    - Subtract 1% for totals between 30-65%
    - Subtract 2% for totals over 66%
    - Record canopy cover percentile in deployment datasheet

6.4.9 *Site Maintenance*

All monitoring locations and deployment strategies are maintained as needed to prevent burial in sediment or excess accumulation of debris that could affect temperature measurements.

6.5 Data Download

Data from the logger is downloaded as described in the instrument SOP (e.g., LWRD 2020) three times per year: typically in January, May, and September. The data file is named using the site ID, underscore, "Temp" for temperature deployment, the date the deployment began (YYYYMMDD format), underscore, "to", underscore, the date the deployment ended (YYYYMMDD format). For example SW011_Temp_20191215_to_20200315 is the temperature deployment data file for site SW011 for the date range December 15, 2019 through March 15, 2020. The data file is saved as a raw data file (format depends on the logger; e.g., HOBO temperature logger is in .hobo format) and as an Excel file (.csv, .xls, or .xlsx format) on the LWRD field laptop C:\CTM folder. The Excel file (.csv, .xls, or .xlsx format) is also saved on the LIBC Z:\ drive for data screening and use. See Section 9.1 for details on file saving and location.

6.6 Sampling Activity Flowchart

Personnel responsible for implementing the CTM Project will follow the deployment, operation, and maintenance steps. Detailed instructions are provided in the section referred, and in decision trees attached as Appendix B.

1. Prior to initial logger deployment in the field, verify logger accuracy using two-point accuracy check (Section 7.2).
2. Field deployment:
    a. Prepare loggers for deployment (Section 6.3).
    b. Program loggers to take measurement every 30 minutes (SOP).
    c. Deploy loggers in the field (Section 6.4).
3. Retrieve loggers from the field for triannual data download and QA/QC activities (January, May, September):
    a. Prepare bucket of room-temperature water.
    b. Gather supplies for retrieval of loggers from the field.
    c. Record date and time logger retrieved on deployment/retrieval datasheet.
    d. Observe and record logger condition on deployment/retrieval datasheets: is logger fouled, buried in sediment, or dewatered?
4. In the lab:
    a. Download data (Section 6.5).
    b. Triannual accuracy checks (Section 7.3):
        - Conduct "dirty logger check" and calculate net sensor drift for the end of the previous logging quarter.

- Clean loggers, conduct “clean logger check” and calculate
    - Sensor error caused by fouling.
    - Sensor error caused by calibration drift.

c. Calculate total sensor error (Section 7.3.5).

- Sum absolute value of sensor error due to fouling and sensor error due to calibration drift.
- If acceptance criterion exceeded, correct data by correction factor(s) (Section 7.5 and 9.4).

d. Prepare logger for re-deployment (Section 6.3).

e. Redeploy logger in the field. Record observations, time, date and logger location on deployment/retrieval datasheets.

f. Determine average canopy cover using a spherical densiometer (Section 6.4.8). Record on deployment/retrieval datasheets.

5. Annually (September) verify logger accuracy using two-point accuracy check (Section 7.2).

a. First conduct “dirty logger check” and “clean logger check” as part of the triannual accuracy checks (Section 7.3).

b. Use “clean logger readings” as room-temperature water bath check.

c. Conduct Ice water bath check.

d. Calculate average sensor error.

- If acceptance criterion exceeded, conduct corrective actions (Section 7.5), correct data by correction factor(s) (Section 9.4) and/or return logger to manufacturer.

e. Check logger precision. Acceptance criteria for difference in maximum to minimum logger temperature readings collected during Clean QC/room-temperature water bath check and ice water bath check is ≤0.2°C.

- If acceptance criterion exceeded, conduct corrective actions (Section 7.5) and/or return logger to manufacturer.

f. Prepare logger for re-deployment (Section 6.3).

g. Redeploy logger in the field. Record observations, time, date, and logger location on deployment/retrieval datasheets.

h. Determine average canopy cover using a spherical densiometer (Section 6.4.8). Record on deployment/retrieval datasheets.

6. Data management (Section 9):

a. Remove measurements prior to deployment and after removal of logger from the site to eliminate any air temperature measurements.

b. Remove measurements within 1-hour of deployment to eliminate any water temperature measurements before equilibration.

c. Visually check data for data errors or data gaps.
d. Use summary statistics and automated checks to screen for data errors.
e. Remedy any data errors or suspect data on a case-by-case basis:
    - Leave as is.
    - Exclude from data analysis.
    - Modify or adjust by constant factor or interpolation (Section 9.4, Table 9.2).
f. Ensure that data are identified with the appropriate qualifier (Section 9.7.2).

7. Summary Statistics:
    a. 7-day average of the daily maximum value (7DADM) calculated for all freshwater sites.
    b. 1-day maximum value calculated for all marine sites.
8. Reports:
    a. As part of the Water Quality Assessment Report, summary statistics will be compared with Lummi Nation Water Quality Standards.

7. Quality Assurance and Quality Control Requirements (B5)

Quality Assurance and Quality Control (QA/QC) procedures include logger calibration by the manufacturer, triannual data download and accuracy checks, and annual two-point accuracy check in the lab.

7.1 Logger Calibration (B7)

The continuous temperature loggers will be calibrated by the manufacturer prior to deployment, and as needed per the manufacturer's specifications or as outlined in the equipment SOP (e.g., LWRD 2020). If accuracy check checks fail to meet the acceptance criteria and corrective measures do not solve the problem, the logger will be returned to the manufacturer for recalibration or replacement. The minimum logger recalibration or replacement schedule, if any, is listed in the SOP for the continuous temperature loggers.

7.2 Annual Two-Point Accuracy Check

Prior to initial deployment of the continuous temperature loggers and annually thereafter, ideally in September, a two-point accuracy check will be conducted in the laboratory. The two-point accuracy check involves comparison of the logger's temperature reading to the temperature reading of a National Institute of Standards and Technology (NIST) traceable thermometer using two water baths: ice water and room temperature water. The acceptance criterion for the accuracy check is ±0.5°C. In September, data download, the triannual accuracy checks, and the annual two-point accuracy check are conducted. The triannual accuracy check activities are conducted first with the Clean Logger Check (Section 7.3.4) to fulfill the Room-Temperature Water Bath (Section 7.2.3) portion of the annual two-point accuracy check. All loggers can be checked at one time to consolidate time needed for accuracy check activities.

The two-point accuracy check should also be performed in the lab when sensor error caused by calibration drift exceeds ±0.5°C or if highly variable calibration drift is suspected.

7.2.1 *Equipment*

The following equipment are needed for the two-point accuracy check:

- Two ice chests or insulated containers
- Ice
- Tap water
- Reference thermometer that meets requirements listed in Section 7.6
- Stirrer (armored thermometer case or wooden stick)
- Data loggers to be accuracy checked (strapped together and to a weighted object)

7.2.2 *Ice Water Bath*

The ice water bath prepared as follows:

1. Program temperature loggers to collect temperature measurement at 10 second intervals beginning on the minute (e.g., 11:00:00, 11:00:10, 11:00:20, and so on (see instrument SOP for instructions). Name the file with the site ID (where the logger is deployed when in the field), underscore, the date in YYYYMMDD format, underscore, "IceQC" (e.g., SW011_20200315_IceQC)
2. Fill an ice chest 1/3-1/2 full of ice.
3. Place continuous temperature loggers in ice and cover with additional ice.
4. Add water to the ice chest until even with the top of the ice.
5. Let stand 30 minutes for equilibration.
6. Place NIST-traceable reference thermometer in ice bath and allow to equilibrate. **NOTE:** Agitate bath gently during equilibration and during temperature readings to avoid temperature stratification.[3]
7. Record ten temperature readings from the reference thermometer at 20-second intervals (e.g., 11:00:00, 11:00:20, 11:00:40, and so on).
8. Remove temperature loggers and download data.
9. Calculate difference in readings between reference thermometer and temperature logger. Calculate mean difference in readings to determine accuracy/bias. Calculate standard deviation and maximum-minimum difference for logger readings to determine precision at 0°C.

7.2.3 *Room-Temperature Water Bath*

The room-temperature water bath should be prepared as follows. Note that the Clean Logger Check (Section 7.3.4) can serve as the room-temperature water bath when conducting annual accuracy checks in September. This room-temperature water bath check will be conducted prior to the first deployment of a logger at a site.

1. Fill an ice chest or bucket with water and let sit overnight to reach room temperature.
2. Stir bath gently for five minutes prior to beginning temperature readings and during temperature readings to avoid temperature stratification.[3]
3. Program temperature loggers to collect temperature measurement at 10 second intervals (see instrument SOP). Name the file with the site ID (where the logger is deployed when in the field), underscore, the date in YYYYMMDD format, underscore, "WarmQC" (e.g., SW011_20200315_WarmQC).

[3] Agitation of the bath can be accomplished using manual, gentle stirring or a device that will circulate or agitate the water, including an air circulator (such as is used in a fish tank).

    - Note that the file name will have “CleanQC” instead of “WarmQC” when the two-point accuracy check is conducted immediately after the triannual accuracy checks.
4. Place continuous temperature loggers and NIST-traceable reference thermometer in water. Let stand 30 minutes for equilibration. **NOTE:** Agitate bath gently during equilibration and during temperature readings to avoid temperature stratification.[3]
5. Record ten temperature readings at 20-second intervals.
6. Remove temperature loggers and download data.
7. Calculate difference in readings between reference thermometer and temperature logger. Calculate mean difference in readings to determine accuracy/bias. Calculate standard deviation and maximum-minimum difference for logger readings to determine precision at room temperature.

7.2.4 *Best Practices*

Notes to keep in mind during annual two-point accuracy check:

- Do not allow the temperature loggers or reference thermometer to touch the sides of the bath.
- Keep the bulb of the reference thermometer and the temperature sensor of the logger at the same level in the water. If multiple temperature loggers are checked at once, they can be bundled together for convenience.
- Agitating the baths continuously while measurements are being made is required. It takes only 1-2 minutes for a bath to develop thermal stratification (Schuett-Hames et al. 1999).[3]

7.2.5 *Acceptance Criteria*

Calculate the mean difference for the two-point accuracy check using the difference in average temperature measured in the ice water bath and the room-temperature water bath. The acceptance criterion for the accuracy check is ±0.5°C. If an accuracy check reveals the mean difference between the reference temperature and the measured temperature is greater than 0.5°C, redo the two-point accuracy check using best practices (see Table 7.1, Section 7.2.4, Section 7.5). If logger accuracy exceeds the acceptance criterion, the logger is returned to the manufacturer for recalibration or replacement.

If the difference between the maximum logger reading and minimum logger reading for either the ice water bath or room temperature bath exceeds 0.2°C, redo the two-point accuracy check using best practices and/or return the logger to the manufacturer for recalibration or replacement (see Table 7.1, Section 7.2.4, Section 7.5). Contact the manufacturer for guidance if the precision does not meet manufacturer-provided precision specifications but does not exceed the CTM Project precision criteria (i.e., difference between maximum and minimum readings in stable temperature water ≤0.2°C).

7.3 Triannual Accuracy Check

An accuracy check will take place three times per year in January, May, and September. The accuracy check involves comparison of the temperature measurement taken by the continuous temperature logger to measurements taken by a reference thermometer in a room-temperature water bath. Two types of error will be checked: sensor error caused by fouling and sensor error caused by calibration drift. All loggers can be checked at one time to consolidate time needed for accuracy check activities.

Once per year, typically in September, data download, the triannual accuracy checks, and the annual two-point accuracy check are conducted. The triannual accuracy check activities are conducted first with the Clean Logger Check (Section 7.3.4) used to fulfill the Room-Temperature Water Bath (Section 7.2.3) portion of the annual two-point accuracy check.

7.3.1 *Equipment*

Equipment needed for triannual accuracy checks are as follows:

- One ice chest, insulated container, or bucket
- Tap water
- Stirrer (armored thermometer case or wooden stick)
- NIST-traceable reference thermometer that meets the criteria listed in Section 7.6
- Data loggers to be accuracy checked (strapped together and to a weighted object)

7.3.2 *Sensor Error Determination*

After retrieving the logger from the deployment location, noting any fouling on the field datasheet, returning to the lab and downloading the continuous temperature data from the logger, the logger is checked for sensor error caused by fouling and sensor error caused by calibration drift. In the lab, the temperature measurements from the logger are compared to temperature measurements from the reference thermometer twice: once while the loggers are still fouled from the previous field deployment (“dirty logger temperature”) and once after the loggers have been cleaned (“clean logger temperature”). The average difference in the “dirty logger temperature” compared to the reference thermometer provides the net sensor drift for the end of the previous logging quarter, so provides information as to the accuracy of the temperature measurements at the time the loggers were removed from the site. The difference between the average “dirty logger temperature” and average “clean logger temperature” is the sensor error caused by fouling (i.e., how much error is introduced by the logger becoming dirty while deployed in the field). The average difference in the “clean logger temperature” compared to the reference thermometer provides the calibration drift error, so provides information as to the accuracy of the temperature measurements at the beginning of the next logging quarter when the loggers are redeployed. The absolute value of the sensor error caused by fouling and the calibration drift error is the total error of the logger (Wagner 2006). Detailed methods for this error determination are listed below.

7.3.3 *Dirty Logger Check*

1. After downloading the temperature data from the logger, reprogram the logger to record a temperature measurement every 10 seconds (see instrument SOP). Name the file with the site ID (where the logger is deployed when in the field), underscore, the date in YYYYMMDD format, underscore, "DirtyQC" (e.g., SW011_20200315_DirtyQC)
2. Place the loggers into the room-temperature bucket of water. Place the reference thermometer into the water near, but not touching, the loggers. Allow the loggers and reference thermometer to equilibrate for 30 minutes.
3. Take ten temperature readings at 20-second intervals (3 minutes), recording the time (including seconds) of the measurement and the temperature reading of the reference thermometer.
4. Remove the loggers from the water, and download the temperature data ("dirty QC").
5. Calculate the difference in temporally paired readings between the reference thermometer and temperature logger. Calculate mean difference in readings. This is the net sensor drift for the end of the previous logging quarter. This is the amount of error in the temperature readings of the logger when the logger was removed from the field.
6. Calculate the mean logger temperature reading. This is the initial (dirty) mean logger temperature reading, which will be used in step 7 in Section 7.3.4.

7.3.4 *Clean Logger Check*

1. After downloading the "dirty QC" temperature data from the logger, reprogram the logger to record a temperature measurement every 10 seconds (see instrument SOP). Name the file with the site ID (where the logger is deployed when in the field), underscore, the date in YYYYMMDD format, underscore, "CleanQC" (e.g., SW011_20200315_CleanQC)
2. Note any fouling of the loggers. Clean the loggers in warm water. Use mild dishwashing detergent if necessary.
3. Return the loggers to the room-temperature bucket of water. Place the reference thermometer into the water near, but not touching, the loggers. Allow the loggers and reference thermometer to equilibrate for 30 minutes.
4. Take ten temperature readings in 20-second intervals (3 minutes), recording the time (including seconds) of the measurement and the temperature reading of the reference thermometer.
5. Remove the loggers from the water, and download the temperature data ("clean QC").
6. Calculate the mean logger temperature reading. This is the clean mean logger temperature reading.
7. Calculate the difference between the initial (dirty) mean logger temperature reading calculated in step 6 (prior to cleaning the logger) and the clean mean logger temperature reading calculated in step 11 (after cleaning the logger). This is the sensor

error caused by fouling. This is the amount of error introduced while the logger was in the field due to it becoming dirty.

8. Calculate the difference in temporally paired readings between the reference thermometer and the clean temperature logger. Calculate mean difference in readings. This is the sensor error caused by calibration drift. This is the amount of error in the temperature readings of the logger when the logger is redeployed into the field at the beginning of the subsequent logging quarter.

   NOTE: If the reference temperature changed between the initial (dirty) logger readings and the post-cleaning logger readings, the data can be adjusted by this difference. This can be prevented by preparing the room-temperature bucket the day prior to triannual accuracy checks and by conducting the initial/dirty and clean logger readings on the same day as close in time as possible.

7.3.5 *Total Error and Acceptance Criteria*

The acceptance criterion is ±0.5°C. To calculate total sensor error for the triannual accuracy check, sum the absolute value of:

- Sensor error due to fouling (calculated in step 7 in Section 7.3.4)
- Sensor error due to calibration drift (calculated in step 8 in Section 7.3.4)

Datasheets have been set up in Excel to allow for automatic calculation of error. Field personnel are encouraged to use the Excel datasheets to facilitate error calculation and reduce human error.

Data correction may be needed to ensure that the acceptance criterion is met. Either the accuracy check data can be adjusted or the temperature deployment data can be adjusted prior to use in analysis and reporting.

If the total error exceeds 0.5°C and the average reference thermometer readings were different for the dirty and clean logger checks, adjust the accuracy check data by the difference. The average difference in the reference thermometer readings is subtracted from the logger readings of the period during which the reference thermometer readings were higher. For example, if the average reference thermometer reading was higher for the clean logger check, the average difference in reference thermometer reading is subtracted from each clean logger reading and total error is recalculated.

If the net calibration drift or total error exceeds 0.5°C, the temperature logger readings for the previous logging quarter will need to be adjusted to reduce the error to within the acceptance criterion. See Section 9.4 for data correction details.

If the sensor error caused by calibration drift (calculated in step 8 in Section 7.3.4) alone exceeds the acceptance criterion (±0.5°C), a two-point accuracy check should be conducted and the logger may need to be returned to the manufacturer for recalibration or replacement.

Note that if total sensor error exceeds the acceptance criterion even after data corrections, it may not be necessary to conduct a two-point accuracy check and/or return the logger to the manufacturer for recalibration or replacement. Sensor error caused by calibration drift and sensor error caused by fouling can be corrected for when total sensor error exceeds the acceptance criterion (see Section 9.4).

The acceptance criterion for precision is a difference in maximum-minimum temperature reading collected during two-point accuracy check (each water bath assessed separately) of ≤0.2°C.

7.4 Additional Accuracy Checks

After a temperature logger data download, results will be compared to temperature readings collected from the site during regular water quality monitoring (Lummi Nation Ambient Surface Water Quality Monitoring Project). Summary statistics will be calculated to inform potential changes and improvements to logger deployment location and overall representativeness of sites selected for monitoring projects.

7.5 Acceptance Criteria and Corrective Actions

Cumulative error allowed for the CTM Project is 0.5°C. Table 7.1 summarizes the acceptance criteria for various QA/QC steps, as well as instructions for corrective actions in the event that acceptance criteria are not met.

Table 7.1 Acceptance Criteria and Corrective Actions

Quality Assurance Step	Acceptance Criteria	What to do if acceptance criteria are not met
Two-point accuracy check (Pre-deployment or annual)	±0.5°C	Carefully redo accuracy check. Ensure timing of record collection for the reference thermometer and logger match (note daylight savings time), the water is not stratified, and reference thermometer and logger are not touching the sides of the container. Ensure the bulb of the thermometer and temperature sensor of the logger are at the same level in the water and that sufficient time is allowed for equilibration. If still doesn't meet acceptance criterion, send logger back to manufacturer for recalibration or replacement.

Table 7.1 Acceptance Criteria and Corrective Actions

Quality Assurance Step	Acceptance Criteria	What to do if acceptance criteria are not met
Precision (maximum-minimum logger temperature) calculated during two-point accuracy check	≤0.2°C	Carefully redo accuracy check. Ensure sufficient time is allowed for equilibration. Use an insulated container for accuracy check to ensure water remains same temperature throughout accuracy check. If reference thermometer maximum-minimum temperature reading also varies by more than 0.2°C, replace water and ice (if applicable) in insulated container and redo accuracy check. If reference thermometer temperature continues to vary, logger temperature readings can be adjusted by reference thermometer readings for assessment of precision only (i.e. adjustment will not be used for accuracy assessment).
Triannual accuracy check (Sum of absolute value of the fouling error and calibration drift error)	±0.5°C	Correct logger readings by difference in average reference thermometer readings between clean and dirty logger checks and recalculate error. Correct logger readings by sensor error caused by calibration drift, if even throughout deployment period, and recalculate error. If data correction(s) decreases recalculated total sensor error to below ±0.5°C, note that data corrections are needed prior to data finalization. If correction(s) do not decrease error to below ±0.5°C, data require further review and correction if they are to be used for analysis and reporting. If error caused by calibration drift alone exceeds the acceptance criterion of ±0.5°C or highly variable calibration drift is suspected, the logger undergoes a two-point accuracy check and potentially returned to the manufacturer for recalibration or replacement. See Section 9.4 for details on data correction.

Table 7.2 summarizes potential problems that may be encountered in deploying the temperature loggers, downloading data, or conducting QA/QC activities. Corrective actions are suggested for various potential problems.

Table 7.2 Troubleshooting for Potential Problems

Potential Problem	Corrective Action
Dirty sensor	Clean sensor
Poor connections at monitor or sensor	Tighten connections
Failure in electronics	Replace sensor or monitor
Logger buried or dewatered	To prevent future burial or dewatering, redeploy logger in a location with sufficient water at low flow conditions. Attach logger to a block or buoy to keep it above the sediment, if practicable.
Logger cleaned before obtaining pre-cleaning accuracy check comparison	Estimate error as calibration drift. Flag the logger data as unknown sensor error due to fouling.
Cannot calculate sensor error caused by fouling or sensor error caused by calibration drift (e.g., technical difficulties prevent post-cleaning accuracy check comparison)	Estimate error as net sensor drift for the end of the previous logging quarter (step 5 in Section 7.3.2). Do not redeploy logger if technical difficulties prevent data download or launch.
Logger is excessively dirty (i.e., sensor error caused by fouling consistently exceeds ±0.5°C acceptance criterion during field accuracy checks)	Temperature data will need to be adjusted to correct for sensor error due to fouling (see Section 9.4). Consider changing the logger deployment location to an area that may have reduced fouling. Consider downloading data from this logger more frequently to reduce fouling error at the time of data download.
Sensor error caused by calibration drift appears to be highly variable or exceeds ±0.5°C	Conduct two-point accuracy check. If needed, return to manufacturer for recalibration or replacement.
Logger does not meet QA/QC acceptance criteria	See Section 7.5, Table 7.1.
Rapidly changing conditions during accuracy check	Adjust triannual accuracy check data by difference in average reference thermometer reading and recalculate error. To prevent changing conditions during dirty and clean logger checks, prepare room-temperature bucket the day prior to triannual accuracy checks and conduct dirty and clean logger checks as close together in time as possible in a climate controlled room.

7.6 Requirements of the Reference Thermometer

The reference thermometer used to verify acceptable accuracy of the temperature loggers must meet one of the following criteria:

- NIST-certified,
- Manufacturer-certified as NIST-traceable and carry a current NIST certification, or
- NIST-traceable certification that is no more than 2 years old or still current according to the manufacturer.

In the event that a reference thermometer meeting the required criteria is not available, a secondary standard for the reference thermometer is as follows: NIST-traceable certificate of calibration with expiration date no greater than 5 years prior. The reference thermometer must remain within ±0.2°C of 0°C in ice water bath. Note the use of a reference thermometer meeting the secondary standard in the field datasheets and database.

7.7 Equipment Maintenance (B6)

Equipment maintenance activities are the responsibility of the Water Resources Specialist II, assisted by the Water Resources Technician II and Natural Resources Technician II. Specific information regarding maintenance of the temperature loggers is provided in the instrument SOP. At a minimum, continuous temperature loggers are cleaned three times per year during triannual accuracy checks as specified in Section 7.3.

8. SUPPLIES AND CONSUMABLES (B8)

The Water Resources Specialist II is responsible for ensuring that critical supplies and consumables are ready for use. Equipment is kept in good working order and supplies are regularly inventoried and stocked by the Water Resources Specialist II and Water Resources Technician II to ensure availability. Equipment required for implementation of the CTM Project are stored in the LNR office, lab, and storage locker. Details on supply ordering, stocking levels, and management are provided in the QMP. Details on equipment and supply inspection are listed in the equipment SOPs.

Supplies and consumables used in the CTM Project are listed below.

Data Recording:

- Field laptop
    - Temperature loggers, downloading equipment, and software as specified in the continuous temperature logger SOP (e.g., LWRD 2020)
    - CTM Project accuracy check datasheets (Appendix A)
- Field clipboard with hard copies of CTM Project field datasheets (Appendix A) and waterproof pen and/or pencil
    - Deployment/retrieval datasheets
    - Stream cross-section survey datasheets
- Sandwich bags with site numbers for organizing retrieved loggers

Deployment equipment depends on deployment techniques selected, but may include:

- Heavy-duty (e.g., 120-lb tensile strength) cable
- Zip ties
- Scissors
- Fence posts or rebar
- Fence post driver
- Wire rope clips
- Wrench
- Wire cutters
- Custom-built bricks with eyelets
- Cinder blocks
- Buoys
- PVC pipe and hose clamps
- Logger protective housing made from PVC
- Drill

Accuracy check equipment:

- Buckets, coolers, or insulated containers (2)
- Ice
- Tap water
- Stirrer (armored thermometer case or wooden stick)
- Zip ties
- Weighted object, such as a PVC protective housing
- Reference thermometer
- Timer with seconds (e.g., online clock)

9. DATA MANAGEMENT (B10)

As previously described, data will be downloaded from the loggers as specified in the instrument SOP. A backup of the data will be saved prior to clearing the memory of the logger and reprogramming for triannual accuracy checks. The data will be saved on the field laptop and transferred to secure LIBC servers. Data saved on the LIBC servers are backed up regularly. Data will be screened, data errors identified, and data corrected as needed prior to upload to the Datalogger Database with appropriate metadata. Data are generally only entered into the database if method and quality control activity criteria are met, however data that have been corrected or otherwise modified will be labeled as such in the database or source datasheets.

The Water Resources Specialist II will be responsible for data management of CTM Project data with support and supervision provided by the Water Resources Manager and the Database Manager.

9.1 File Naming and Location

All data collected as part of the CTM Project are saved on secure LIBC servers that are backed up regularly. Files are saved on the C:\ drive of the LWRD field laptop immediately after data download and during triannual laboratory accuracy checks. Files are then saved onto secure LIBC servers on the Z:\ drive for data screening and data verification and validation prior to upload to the Datalogger Database. Files containing final validated data that were uploaded to the Datalogger Database and saved in PDF format and saved in the H:\ drive Digital Archive located at H:\Natural Resources\DA_WaterResources\SurfaceWaterData under the appropriate year and month folders. Datasheets that are not completed directly on the LWRD field laptop, such as deployment datasheets, retrieval datasheets, and stream cross-section surveys are scanned and saved on the Z:\ drive. Paper copies of datasheets are saved in a three-ring binder stored by the Water Resources Specialist II.

Table 9.1 File description, naming convention, format, and location

File description	File name	Format type	Location
Field deployment temperature data	Site ID_Temp_DeploymentStartDateYYYYMMDD _to_DeploymentEndDateYYYYMMDD (e.g., SW011_Temp_20191215_to_20200315)	Raw data format from the logger (e.g., .hobo)	LWRD field laptop: C:\CTM\year (YYYY) data downloads
	Site ID_Temp_DeploymentStartDateYYYYMMDD _to_DeploymentEndDateYYYYMMDD (e.g., SW011_Temp_20191215_to_20200315)	Excel format (.CSV and .XLS or .XLSX)	LWRD field laptop: C:\CTM\year (YYYY) Excel data Z:\GISpublic\JamieM\Datalogger Data\Temperature\Post QAPP Data_2016 and beyond\site ID
Field deployment temperature data with QC information	Site ID_Temp_DeploymentStartDateYYYYMMDD _to_DeploymentEndDateYYYYMMDD_QC (e.g., SW011_Temp_20191215_to_20200315_QC)	Excel format (.XLS or .XLSX)	Z:\GISpublic\JamieM\Datalogger Data\Temperature\Post QAPP Data_2016 and beyond\site ID\QCd data
Field deployment temperature data prepared for upload to Datalogger Database	Site ID_Temp_DeploymentStartDateYYYYMMDD _to_DeploymentEndDateYYYYMMDD_Final (e.g., SW011_Temp_20191215_to_20200315_Final)	Excel format (.XLS)	Z:\GISpublic\JamieM\Datalogger Data\Temperature\Post QAPP Data_2016 and beyond\site ID\QCd data\Export
Accuracy check data download (e.g., dirty or clean logger checks)	SiteID_DateYYYYMMDD_dirtyQC or cleanQC (e.g., SW011_20200315_dirtyQC)	Raw data format from the logger (e.g., .hobo)	LWRD field laptop: C:\CTM\year (YYYY) data downloads
Datasheets	DateYYYYMMDD_QuarterNumberAccuracyCheck_ SiteID (e.g., 20200315_Q1AccuracyCheck_SW011)	Excel format (.XLS or .XLSX)	LWRD field laptop: C:\CTM\year (YYYY) datasheets Z:\GISpublic\JamieM\Datalogger Data\Temperature\Post QAPP Data_2016 and beyond\Datasheets

9.2 QA/QC Data

Both QA/QC data and continuous temperature data for each logger and site are accessible in electronic folders maintained for the CTM Project (see Table 9.1). Data are checked against quality control activity data and are validated according to their quality:

- Final: Data that meet acceptance criteria are considered final data and uploaded to the Datalogger Database for use in analysis and reporting.
- Final (Corrected): Data that require data adjustment or correction are labeled as corrected with explanation of how and why corrected or adjusted in the source spreadsheets. These data are considered final data and uploaded to the Datalogger Database for use in analysis and reporting.
- Rejected: Data that do not meet acceptance criteria or otherwise have poor QA/QC performance are prominently labeled as rejected with the reason why in the source spreadsheets and are not uploaded to the Datalogger Database.

At this time, the Datalogger Database is not able to store QA/QC data. Data corrections and QA/QC information are provided in source datasheets stored in electronic folders for the CTM Project. Only final data that have acceptable data quality for analysis and reporting are uploaded into the Datalogger Database.

9.3 Data Screening and Identification of Data Errors

Prior to inclusion in the database, data are screened for errors based on time, visual checks, and summary statistics.

Pre- and post-deployment observations are removed. Using field notes or datasheets listing the exact time loggers were deployed and recovered, temperature measurements logged prior to deployment and after recovery are removed from the dataset to eliminate air temperature measurements. A one-hour buffer period is also applied; observations within the first hour after deployment are removed to ensure that the logger temperature readings have stabilized and to eliminate any air temperatures that may have been collected.

Data are corrected based on results of triannual field accuracy checks. If field accuracy check data were adjusted by sensor error caused by calibration drift, data for that quarter are corrected for calibration drift by a constant correction factor, if sensor error caused by calibration drift remained steady since the previous accuracy check, or using a linearly interpolated correction factor, if sensor error caused by calibration drift did not remain steady.

If the field accuracy check did not meet the acceptance criterion after data adjustment by calibration drift, data for that quarter are corrected for sensor error caused by fouling. Fouling error can be caused by a single event or gradually over time by visual examination of temperature data graphed over time.

Details on data correction are provided in Section 9.4.

Data will be checked visually and by trend analysis to determine if data errors have taken place or if data gaps are present. The following visual checks will be performed to screen for data errors (EPA 2014):

- Individual data points are plotted by time to check for missing data or abnormalities.
- Water and air temperature are graphically compared. A close correspondence between water and air temperature strongly indicates that the logger was dewatered for that period of time.
- Time permitting; data across years are graphically compared. If data from one year are dramatically different, data errors may be present.

Summary statistics and automated checks are also used to screen for data errors. These include (EPA 2014):

- Calculation of upper and lower 5th percentiles.
- Flagging of data points as suspect if they:
    - Exceed a maximum of 25°C
    - Exceed a minimum of -1°C
    - Exceed a daily change of 10°C
    - Exceed the upper 5th percentile of the overall distribution
    - Fall below the lower 5th percentile of the overall distribution

If data are flagged as suspect, potential errors are investigated and addressed on a case-by-case basis. Suspect data points are cross-checked with air temperatures to determine whether the logger was dewatered during this period.

9.4 Data Correction

After data gaps or errors have been identified, data will be corrected, removed, or left as is on a case-by-case basis. Errors identified during logger deployment, accuracy check, and fouling check can also be corrected prior to data analysis.

In general, data can be corrected by applying a constant correction factor or by linearly interpolating a correction factor. A constant correction factor is applied if sensor error caused by calibration drift remained steady for the entire logging quarter (i.e., calibration error for beginning of logging quarter is compared to calibration error for the end of the logging quarter). A linearly interpolated correction factor is used if a gradual change in either sensor error caused by calibration drift or sensor error caused by fouling has occurred. The correction factor is linearly interpolated from deployment start (e.g., minimum correction) to deployment end (e.g., maximum correction) and the appropriate correction factor is applied to each data point based on time. The correction factor can be either a percentage or integer. A percentage correction factor is recommended as it reduces the occurrence of negative temperature values (Wagner et al. 2006).

Correction factors can also be applied to correct for fouling caused by a single event, if evidenced by a visual inspection of temperature data across time. In this case, a constant correction factor is only applied to the period of time after which the fouling took place (i.e., the correction factor is not applied to the period of time prior to the fouling event).

Table 9.2 Data Correction Actions

Problem	Action
Missing data	Leave blank.
Logger was dewatered or buried in sediment for part of the deployment period	Determine the period during which the problem occurred and exclude these data from the analysis.
Recorded values are off by a constant, known amount	Adjust each recorded value by a single constant value within the correction period. For example, constant calibration drift (Sections 7.2, 7.3, and 7.5)
A large amount of drift is present, and triannual accuracy check acceptance criterion is not met even after data correction (e.g., of reference thermometer difference or constant calibration drift). It is unknown when and by how much the logger readings have drifted (e.g., by fouling or non-constant calibration drift).	Adjust each recorded value by any constant, known amounts (e.g., constant calibration drift). Determine whether drift occurred gradually over time or after an event by visually examining temperature data graphed over time. If gradual drift, linearly interpolate correction factor from deployment start (e.g., zero correction) to deployment end (e.g., maximum correction) and apply appropriate correction factor based on time. This can be done as a percentage or integer. Percentage is recommended as it reduces the occurrence of negative temperature values (Wagner et al. 2006).

9.5 Summary Statistics

Only verified or corrected data are considered validated (final) and are used to calculate summary statistics. Rejected data will not be used in calculation of summary statistics. The seven-day average of the daily maximum value (7DADM) is calculated for all freshwater sites. A daily maximum value is calculated for all marine sites.

9.6 External Data Acquisition (B9)

Although no external data acquisition is currently planned, data from the U.S. Geological Survey (USGS) gage station on the Nooksack River at Ferndale (USGS 12213100) may be acquired and compared with temperature data collected at site SW118 (Nooksack River at Marine Drive). Daily maximum, minimum and average temperature data for the Nooksack River gage station will be downloaded from the USGS website, if used. Any external data used will be clearly marked as such and will include any metadata available.

Continuous temperature data collected by other LNR departments (e.g., Restoration Division) may be used to supplement the data collected under this QAPP. If the temperature data were collected following an approved QAPP, these data may be used in addition to the data collected under this QAPP to determine whether waters meet the Surface Water Quality Standards. All data external to the project detailed in this QAPP will be clearly marked as such and will include any metadata available.

9.7 Data Review and Usability

9.7.1 *Data Review, Verification, and Validation Requirements (D1)*

The QA/QC acceptance criterion of ±0.5°C must be met in order for data to be validated. Data that are not validated due to QA/QC acceptance criteria not being met can be used if data are corrected or modified in order to meet QA/QC.

Details on the data review and correction process are listed in Sections 9.3 and 9.4. Following data review and correction, as needed, the data are verified and validated prior to use for calculation of summary statistics, reporting, and compliance determination.

9.7.2 *Verification and Validation Methods (D2)*

As previously described, water temperature data are generally only entered into the Datalogger Database if method and quality control activity criteria are met. Data that have been corrected or otherwise modified will be uploaded to the database upon validation and corrected and modified data are marked appropriately in the source spreadsheets with all relevant metadata included. Data that are not validated or have been rejected due to poor data quality are not uploaded to the Datalogger Database. The data are clearly marked as rejected with the reason why in the source spreadsheets. If data are entered into the database that do not meet the method and quality control activity criteria or are otherwise suspect, the data are immediately removed from the database. Suspect data marked as such in the source spreadsheets and are reviewed for inclusion in calculations, and rated (validated) for inclusion in the database on a case-by-case basis.

Data qualifiers are noted in the source spreadsheets and include:

- “Validated” and “Final” for data that meet QA/QC requirements without correction factors.
- “Corrected” and “Final” for data that have been modified using correction factors, either by adding an integer or applying a percentage modification.
- “Rejected” for data that have been removed from analysis. Potential reasons for removal include: measurement taken outside of deployment period, measurement taken while logger dewatered or buried in sediment, or excessive error did not meet QA/QC acceptance criterion and data could not be adjusted to account for error.

As described above, only Final data are uploaded into the Datalogger Database. Rejected data are not uploaded into the Datalogger Database. Qualifier information, including data corrections and adjustments, are included in source spreadsheets but are not currently accessible in the Datalogger Database directly.

The Water Resources Specialist II is responsible for verifying and validating project data and information. The Water Resources Specialist II is responsible for ensuring all QA/QC protocols are followed, and for quantifying or qualifying data quality to data users.

Standard forms used for data entry are attached as Appendix A.

9.7.3 *Reconciliation with User Requirements (D3)*

Verified data are validated using the grading system described in Section 9.7.2 to indicate a level of data quality. All data are stored with data correction and modification information and appropriate metadata in source spreadsheets or the Datalogger Database. In general, the uncertainty of the validated data is ±0.5°C due to acceptance criteria for QA/QC activities.

From 2009 to 2015, continuous temperature monitoring data were collected for informational purposes prior to the development of this QAPP. As no written and approved QA/QC procedures were in place at the time of the previous data collection, the previous data will not be included in summary reports of the data collected for the CTM Project as outlined in this QAPP. If previously collected data are used for comparison, these data will be clearly marked as "suspect" or otherwise delineated that they were collected without a written and approved QAPP. Data collected prior to QAPP development will not be used for any decisions leading from data collected under the CTM Project as outlined in this QAPP.

The CTM Project is an ongoing project and is not designed to prove or disprove specific hypotheses.

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10. OVERSIGHT AND REPORTING

10.1 Assessments, Oversight, and Response Actions (C1)

Section 1 of this QAPP and the QMP list the key personnel and their responsibilities. In summary, the person conducting the monitoring (primarily the Water Resources Specialist II, but also the Water Resources Technician II and Natural Resources Technician II) is responsible for performing all inspections, accuracy checks, and quality control activities. The Water Resources Specialist II is responsible for screening the data, applying correction factors as necessary, and uploading data to the Datalogger Database, with support from the Database Manager. The Water Resources Specialist II reports to the Water Resources Manager, who ensures that QA/QC objectives and reporting requirements are achieved.

Operator error and equipment problems detected during accuracy check and other QA/QC activities will initiate actions to correct the problem (Section 7.5). Quality control activities also inform potential data correction factors that may be applied, as appropriate (Section 9.4). Project action limits and assessment are described in the QMP.

10.2 Reports to Management (C2)

The Water Resources Specialist II is responsible for evaluating monitoring and quality control data and reporting to the Water Resources Manager regularly and as needed if problems are detected. The Water Resources Specialist II/Planner performs periodic Quality Assurance audits that the Water Resources Manager evaluates for compliance with the project goals. When problems are detected and not resolved through standard practices or are of a larger nature than the staff conducting water quality sampling typically address, the Water Resources Specialist II and the Water Resources Manager will jointly develop an action plan to remedy the problem with clear roles, responsibilities, and timelines.

The Water Resources Specialist II prepares a Water Quality Assessment Report that summarizes the collected water temperature data for a two-year period, compares the results with the Lummi Nation water quality standards and the data for the period of record, and documents attainment or non-attainment of designated uses. These reports are reviewed and approved by the Water Resources Manager and the LNR Deputy Director, and the approved reports are transmitted to the EPA every-other year by March 31st of the year following the two-year reporting period. The Water Resources Manager submits semi-annual (twice per year) progress reports to the EPA Project Officer that describe program status, problems, remedies, and schedules.

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12. Acronyms and Abbreviations

7DADM	7-Day Average of the Daily Maximum
CTM	Continuous Temperature Monitoring [Project]
CWRMP	Comprehensive Water Resources Management Program
EPA	Environmental Protection Agency
LAR	Lummi Administrative Regulation
LCL	Lummi Code of Laws
LIBC	Lummi Indian Business Council
LNR	Lummi Nation Natural Resources Department
LWRD	Lummi Nation Natural Resources Department, Water Resources Division
NIST	National Institute of Standards and Technology
QAPP	Quality Assurance Project Plan
QA/QC	Quality Assurance/Quality Control
QMP	Quality Management Plan
SOP	Standard Operating Procedure
USGS	U.S. Geological Survey
WQM	Water Quality Monitoring [Program]

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13. APPENDICES

Appendix A. Data Sheets for Lab and Field Accuracy Checks

Note that these data sheets should be filled in using Microsoft Excel in order to make use of the built-in calculation of error. Required calculations are listed on the data sheets in the event that data sheets are printed out and filled in by hand in the field.

Appendix B. Decision Trees

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Appendix A. Data Sheets

Note that these data sheets should be filled in using Microsoft Excel in order to make use of the built-in calculation of error. Required calculations are listed on the data sheets in the event that data sheets are printed out and filled in by hand in the field.

Excel versions of these data sheets are saved here:

\\libc.lummi-nsn.net\LIBCDFS\Global\Natural Resources\Public\WaterResourcesDivision\Hanna\SOPs and QAPPs\QAPPs\Continuous temp monitoring\Datasheets

Continuous Temperature Monitoring Project
Logger Deployment/Retreival Datasheet

Use this side for logger retrieval

Date	
Names	

Site number	Logger S/N	Time	Retreived?	Dewatered?	Buried in Sediment?	Fouled?	Site Notes
			❑	❑	❑	❑	
			❑	❑	❑	❑	
			❑	❑	❑	❑	
			❑	❑	❑	❑	
			❑	❑	❑	❑	
			❑	❑	❑	❑	
			❑	❑	❑	❑	
			❑	❑	❑	❑	
			❑	❑	❑	❑	
			❑	❑	❑	❑	

Figure 13.1 Continuous Temperature Monitoring Project Logger Deployment/Retrieval Datasheet (side 1). Logger retrieval datasheet.

Continuous Temperature Monitoring Project
Logger Deployment/Retreival Datasheet

Date	
Names	

Use this side for logger deployment

Site number	Logger S/N	Time	Densiometer Readings and Canopy Cover Calculations							
			N	E	S	W	Sum of N+E+S+W	x1.5	Correction Factor Applied*	% Canopy Cover
Site notes:										
Site notes:										
Site notes:										
Site notes:										
Site notes:										
Site notes:										
Site notes:										
Site notes:										
Site notes:										
Site notes:										

*Canopy cover correction factors: subtract 1% for totals between 30-60% and subtract 2% for totals more than 66%

Figure 13.2 Continuous Temperature Monitoring Project Logger Deployment/Retrieval Datasheet (side 2). Logger redeployment datasheet with densiometer reading and canopy cover calculations.

Annual 2-Point Accuracy Check Data Sheet
Continuous Temperature Monitoring Project

Note: Blue shaded sections will be automatically calculated when data entered (in Excel)

Date	
Serial Number of Logger	
Serial Number of Reference Thermometer	

Step 1. If logger was previously deployed in the field, complete Quarterly Accuracy Check Data Sheet first

Step 2. Conduct Ice Water Bath Accuracy Check by collecting 10 paired readings of the temp loggers and reference thermometer in 20 second intervals ("Ice QC")

Time (HH:MM:SS)	Logger Temperature (deg C)	Reference Temperature (deg C)	Difference in Temperature Readings
			0
			0
			0
			0
			0
			0
			0
			0
			0
			0
Error at 0°C			0

Step 3. Conduct Room-Temperature Water Bath Accuracy Check by collecting 10 paired readings of the temp loggers and reference thermometer in 20 second intervals ("Warm QC" or "Clean QC")*

***Quarterly Clean Logger Check data used here automatically. If conducting two-point accuracy check without quarterly accuracy check (i.e., for initial deployment), overwrite links in cells for Room Temperature Bath Check**

Time (HH:MM:SS)	Logger Temperature (deg C)	Reference Temperature (deg C)	Difference in Temperature Readings
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
Error at room temperature			0

2-Point Mean Error (average of error at 0°C and room temperature)	0

Summary Table

Temperature	Error (accuracy)	Max-Min Logger Temp (precision)	Standard Deviation (precision)
0 degrees C (ice)	0	0	#DIV/0!
Room temperature	0	0	0

2-point mean error	0

****If 2-point mean error is >0.5°C, consult QAPP for corrective actions and next steps****

****If Max-Min Logger Temp is >0.2°C, consult QAPP for corrective actions and next steps****

Annual 2-Point Accutacy Check Calculation instructions (for printed datasheet)

Step 2. Calculate difference:
Reference Temp-Logger Temp
for each pair.

Calculate average (Error at 0°C):
sum of differences divided by 10

Also enter Error at 0°C in the summary table below.

Step 3. Calculate difference:
Reference Temp-Logger Temp
for each pair.

Calculate average (Error at room temperature):
sum of differences divided by 10

Also enter Error at room temperature in the summary table below.

Step 4. Average errors:
(Error at 0°C + Error at Room Temp)/2
Also enter into the Summary Table below

Step 5. Enter error (accuracy) from calcs above.
Calculate difference between maximum and minimum logger temperature:
Max Logger Temp - Min Logger Temp
Calculate standard deviation:
√((Σ(xi-μ)^2)/10)
xi=each logger temp reading
μ=mean logger temp
Recommended to calculate this in Excel

Figure 13.3 Annual Two-Point Accuracy Check Data Sheet for use prior to initial deployment and during annual laboratory check. This Excel spreadsheet will automatically calculate values in blue and gray.

Triannual Accuracy Check Data Sheet
Continuous Temperature Monitoring Project

Date	
Persons Conducting Work	
Site Number	
Serial Number of Logger	
Previous Calibration Drift	

Serial Number of Reference Thermometer used	

Field Observations (from deployment/retrieval datasheet)			
Date removed		Time removed	
Was the logger buried in sediment?		☐ Yes	☐ No
Was the logger dewatered?		☐ Yes	☐ No
Is the logger visibly fouled?		☐ Yes	☐ No
If fouled, describe fouling:			

Step 1. Conduct "Dirty Logger Check" by collecting 10 paired readings of the temp loggers and reference thermometer in 20 second intervals ("Dirty QC")

Time (HH:MM:SS)	Temp Logger (deg C)	Reference Thermometer (deg C)	Difference in Temperature Readings
			0
			0
			0
			0
			0
			0
			0
			0
			0
			0
Net Sensor Drift for previous logging quarter			0

Step 2. Clean logger with mild detergent (note any fouling prior to cleaning**)**

Step 3. Conduct "Clean Logger Check" by collecting 10 paired readings of the temp loggers and reference thermometer in 20 second intervals ("Clean QC")

Time (HH:MM:SS)	Temp Logger (deg C)	Reference Thermometer (deg C)	Difference in Temperature Readings
			0
			0
			0
			0
			0
			0
			0
			0
			0
			0
Calibration Drift Error (clean logger accuracy)			0
Fouling Error (difference in temp dirty to clean)			#DIV/0!

Step 5a. Adjusted Dirty QC data: corrected for reference temperature difference (automatically corrected if appropriate)

Adjusted Temp Logger (deg C)	Adjusted Reference Thermometer (deg C)	Difference in Adjusted Temperature Readings
#DIV/0!	#DIV/0!	#DIV/0!
#DIV/0!	#DIV/0!	#DIV/0!
#DIV/0!	#DIV/0!	#DIV/0!
#DIV/0!	#DIV/0!	#DIV/0!
#DIV/0!	#DIV/0!	#DIV/0!
#DIV/0!	#DIV/0!	#DIV/0!
#DIV/0!	#DIV/0!	#DIV/0!
#DIV/0!	#DIV/0!	#DIV/0!
#DIV/0!	#DIV/0!	#DIV/0!
#DIV/0!	#DIV/0!	#DIV/0!
		#DIV/0!

Dirty QC Temperature readings adjusted by

#DIV/0!	degrees C

(value subtracted from both logger and reference temp)

Step 5b. Adjusted Clean QC data: corrected for reference temperature difference (automatically corrected if appropriate)

Adjusted Temp Logger (deg C)	Adjusted Reference Thermometer (deg C)	Difference in Adjusted Temperature Readings (calibration drift)
#DIV/0!	#DIV/0!	#DIV/0!
#DIV/0!	#DIV/0!	#DIV/0!
#DIV/0!	#DIV/0!	#DIV/0!
#DIV/0!	#DIV/0!	#DIV/0!
#DIV/0!	#DIV/0!	#DIV/0!
#DIV/0!	#DIV/0!	#DIV/0!
#DIV/0!	#DIV/0!	#DIV/0!
#DIV/0!	#DIV/0!	#DIV/0!
#DIV/0!	#DIV/0!	#DIV/0!
#DIV/0!	#DIV/0!	#DIV/0!
		#DIV/0!
		#DIV/0!

Clean QC Temperature readings adjusted by

#DIV/0!	degrees C

(value subtracted from both logger and reference temp)

Figure 13.4 Triannual Accuracy Check Data Sheet (page 1) for calculation of sensor error caused by fouling and sensor error caused by calibration drift. This Excel spreadsheet will automatically calculate values in blue and gray.

Triannual Accuracy Check Data Sheet

Continuous Temperature Monitoring Project

Step 4. Calculate Error

Error Category	Error	Acceptance Criteria	Data correction needed?	If yes, what correction?	
A. Reference temperature difference (dirty minus clean)	#DIV/0!	0	#DIV/0!	#DIV/0!	Step 5. Adjust clean OR dirty logger check data to correct for change in reference temperature during the accuracy check (automatic)
B. Net Sensor Drift for previous logging quarter	0	0.5	No	Adjust temperature deployment data by calibration drift and/or fouling error for previous quarter to reduce error to within Project limits	
C. Fouling error	#DIV/0!	0.5	#DIV/0!	Adjust temperature deployment data by fouling error for previous quarter to reduce error to within Project limits	
D. Calibration drift	0	0.5	No	1) Adjust temperature deployment data by calibration drift for previous quarter to reduce error to within Project limits. 2) CONDUCT 2-POINT ACCURACY CHECK and see QAPP for details	
E. Total (absolute) error	#DIV/0!	0.5	#DIV/0!	1) Adjust clean or dirty logger check data to correct for change in reference temperature during accuracy check (Step 5)	

Step 6. Re-Calculate Error after Adjustment in Step 5

Error Category	Error (After Correction)	Acceptance Criteria	Data correction needed?	If yes, what correction?	
A2. Reference temperature difference (dirty minus clean)	#DIV/0!	0	#DIV/0!	#DIV/0!	If Error is not zero, go back and ensure that reference temperature correction factor was properly applied in Step 5
B2. Net Sensor Drift for previous logging quarter	#DIV/0!	0.5	#DIV/0!	Adjust temperature deployment data by calibration drift and/or fouling error for previous quarter to reduce error to within Project limits	
C2. Fouling error	#DIV/0!	0.5	#DIV/0!	Adjust temperature deployment data by fouling error for previous quarter to reduce error to within Project limits	
D2. Calibration drift	#DIV/0!	0.5	#DIV/0!	1) Adjust temperature deployment data by calibration drift for previous quarter to reduce error to within Project limits. 2) CONDUCT 2-POINT ACCURACY CHECK and see QAPP for details	
E2. Total (absolute) error	#DIV/0!	0.5	#DIV/0!	Adjust temperature deployment data by calibration drift and/or fouling error for previous quarter to reduce error to within Project limits.	

Figure 13.5 Triannual Accuracy Check Data Sheet (page 2) for use during accuracy checks and calculation of sensor error caused by fouling and sensor error caused by calibration drift. This spreadsheet (when open in Excel) will automatically calculate values in blue and provide color-coded (red or green) prompts for data corrections that may be needed.

Triannual Accuracy Check Calculation Instructions
(for printed datasheet)

Step 1. For each paired measurement, calculate the difference:
Ref Thermometer - Temp Logger
Calculate Average of differences:
Sum of Difference in Temp Readings/10
for Net Sensor Drift for previous logging quarter. Also enter in Step 4 table row B error

Step 2. Clean logger

Step 3. For each paired measurement, calculate the difference:
Ref Thermometer - Temp Logger
Calculate Average of differences:
Sum of Difference in Temp Readings/10
for Calibration Drift Error (clean logger accuracy). Also enter in Step 4 table row D error.
Calculate difference between mean dirty logger temp and clean logger temp:
Average (Temp Logger Step 1 - dirty) - Average (Temp Logger Step 3 - clean)
for Fouling Error. Also enter in Step 4 table row C error.

Step 4. Calculate error summary table.
A. Calculate difference between mean dirty reference thermometer temp and clean reference thermometer temp:
Average (Ref Therm Step 1 - dirty) - Average (Ref Therm Step 2 - clean)
If Error A > 0, go to Step 5a
If Error A < 0, go to Step 5b
If Error A = 0, no adjustments are needed

B. Enter Net Sensor Drift for previous logging quarter into row B error from step 1.
If Error B > 0.5, see correction details in Step 4 table

C. Enter Fouling Error into row C error from Step 3.
If Error C > 0.5, see correction details in Step 4 table

D. Enter Calibration Drift into row D error from Step 3.
If Error D > 0.5, see correction details in Step 4 table

E. Calculate Total (absolute) Error:
ABS[Fouling Error (C)]+ABS[Calibration Drift (D)]
If Total Error E > 0.5, see correction details in Step 4 table and adjust by Error A.

Step 5. Adjust clean OR dirty logger check data.

If Error A > 0, adjust dirty QC temperature readings (both logger and reference temperature) by subtracting the difference (Step 4 Row A error) in **Step 5a.** Recalculate difference in paired readings (Adjusted Reference Thermometer - Adjusted Logger) and calculate average difference (Sum of Difference in Adjusted Temperature Readings/10). Enter adjusted Net Sensor Drift for previous logging quarter into row B2 Error in Step 6 table.

If Error A < 0, adjust clean QC temperature readings (both logger and reference temperature) by subtracting the difference (Step 4 Row A error) in **Step 5b.** Recalculate difference in paired readings (Adjusted Reference Thermometer - Adjusted Logger) and calculate average difference (Sum of Difference in Adjusted Temperature Readings/10). Enter adjusted Calibration Drift Error (clean logger accuracy) into row D2 Error in Step 6 table.

Re-calculate difference between mean dirty logger temp and clean logger temp using adjusted data from steps 5a or 5b:
Average (Temp Logger Step 1 - dirty) - Average (Temp Logger Step 3 - clean)
for Adjusted Fouling Error. Also enter in Step 6 table row C2 error.

Step 6: Re-calculate error after 5a/5b adjustments

A2. Calculate difference between mean dirty reference thermometer temp and clean reference thermometer temp:
Average (Ref Therm Step 1 - dirty) - Average (Ref Therm Step 2 - clean)
*This error should now be 0 if adjustments were correctly applied in Step 5.

B2. Enter Net Sensor Drift for previous logging quarter into row B2 error from Step 5a.
If Error B2 > 0.5, see correction details in Step 6 table

C2. Enter Fouling Error into row C2 error from Step 5.
If Error C2 > 0.5, see correction details in Step 6 table

D2. Enter Calibration Drift into row D2 error from Step 5b.
If Error D2 > 0.5, see correction details in Step 6 table

E2. Re-calculate Total (absolute) Error (E2 Error in Step 6 table):
ABS[Fouling Error (C2)]+ABS[Calibration Drift (D2)]
If Total Adjusted Error E2 > 0.5, see correction details in Step 6 table.

Figure 13.6 Triannual Accuracy Check Data Sheet (page 3) for use during accuracy checks and calculation of sensor error caused by fouling and sensor error caused by calibration drift. This spreadsheet provides calculation instructions for triannual accuracy checks when datasheets are printed (i.e., not filled in on field laptop in Excel).

Cross-Section Survey Datasheet **Continuous Temperature Monitoring Project**

Date		Names		Site ID	
Description of cross-section location					

Cross-Section Test

Temperature (°C)	Horizontal Increment number ↓				
Vertical Increment ↓	1	2	3	4	5
Water Surface (top 6 inches)					
6 inches above bottom					

Cross-Section Test Summary

Maximum Temperature	
Minimum Temperature	
Difference	
If difference is >0.5°C, conduct full cross-section survey in datasheet below	

Cross-Section Survey

Cross-section width	
Number of horizontal increments	
Width of horizontal increments	

Maximum depth	
Number of vertical increments	
Height of vertical increments	

Temperature (°C)		Horizontal increment number ↓									
		1	2	3	4	5	6	7	8	9	10
		Distance from left bank (feet) ↓									
Vertical increment number ↓	Depth from surface (feet) ↓										
1											
2											
3											
4											
5											
6											
7											
8											
9											
10											

	Hand calculated	Excel auto-calculated
Maximum Temperature (°C)		0
Minimum Temperature (°C)		0
Difference (max-min)		0

	Excel auto-calculated
Mean temperature (°C)	#DIV/0!
Standard Deviation	#DIV/0!

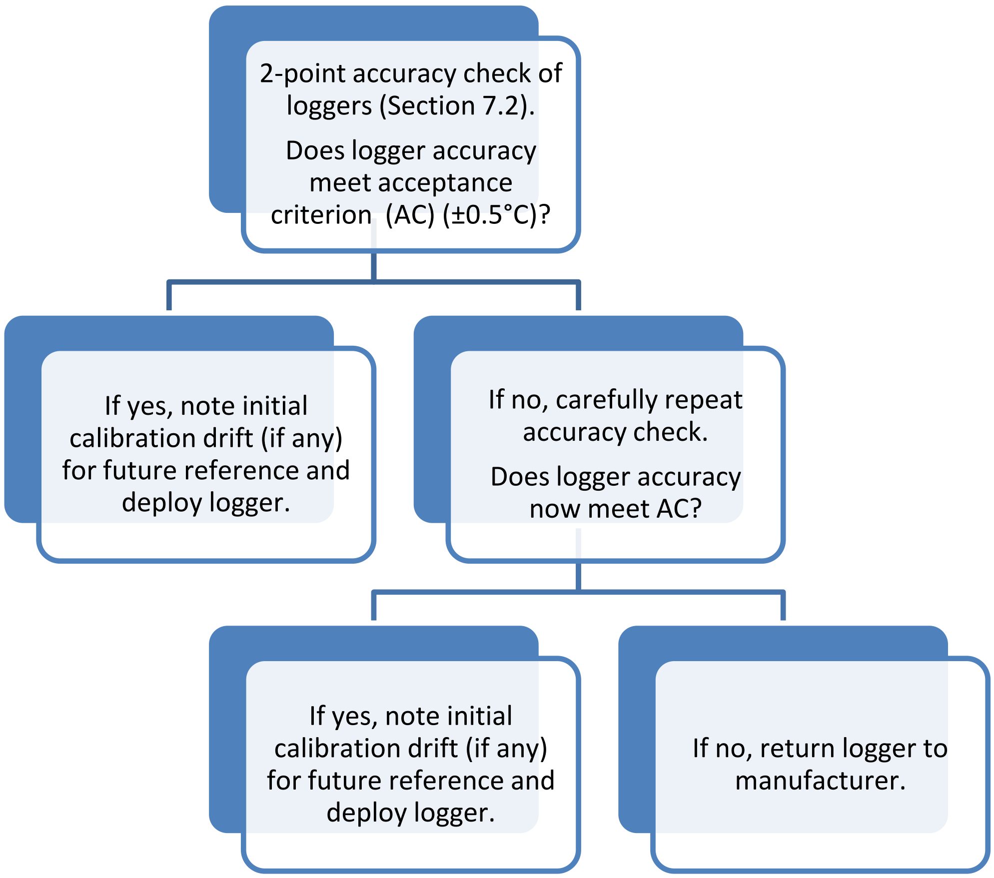
Determine whether logger is deployed at representative location of this reach. See CTM Project QAPP for details.

Figure 13.7 Stream cross-section survey datasheet for use in determining representativeness of temperature logger deployment location and horizontal and vertical stratification.

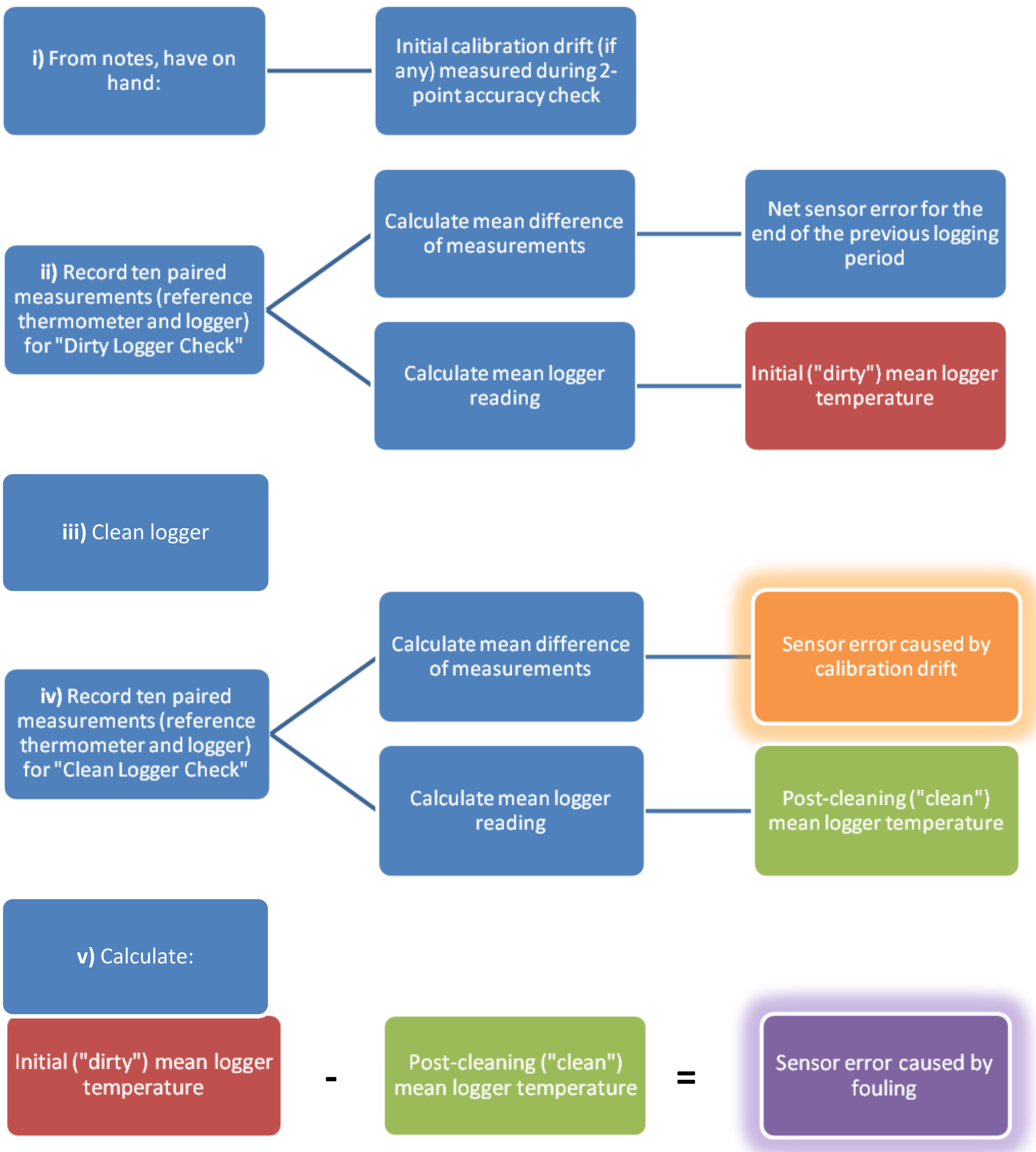
Appendix B. Decision Trees

This appendix includes decision trees for accuracy check prior to initial logger deployment in the field and annually, conducting triannual accuracy checks (including calculation of total sensor error), and determining whether data corrections are needed.

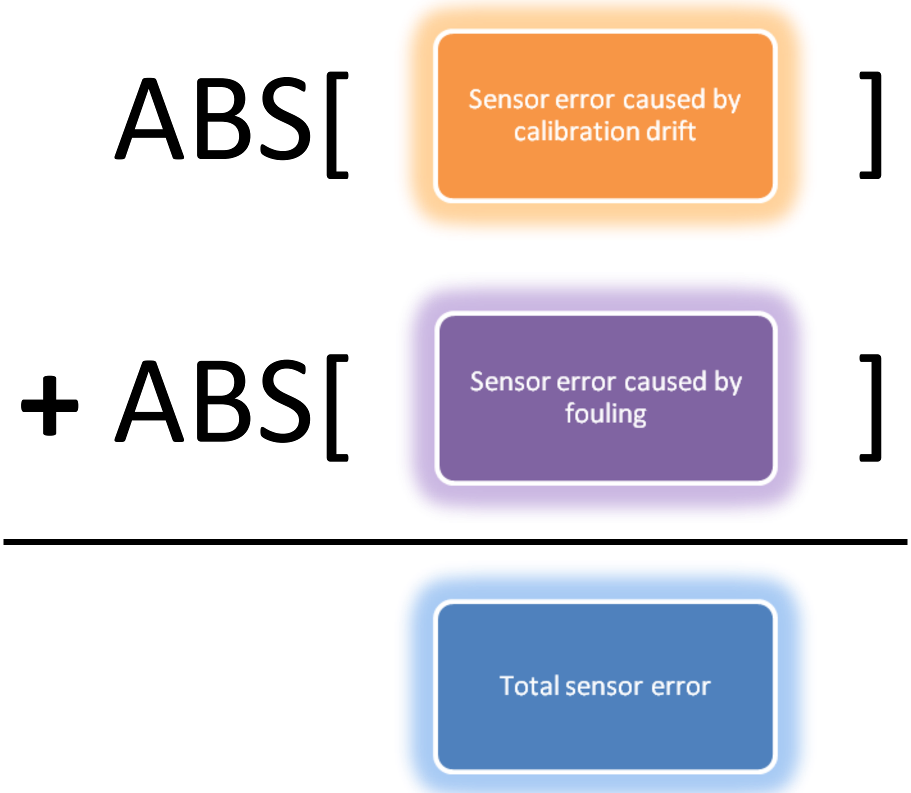
1) Accuracy check prior to initial logger deployment in the field or annually in September:



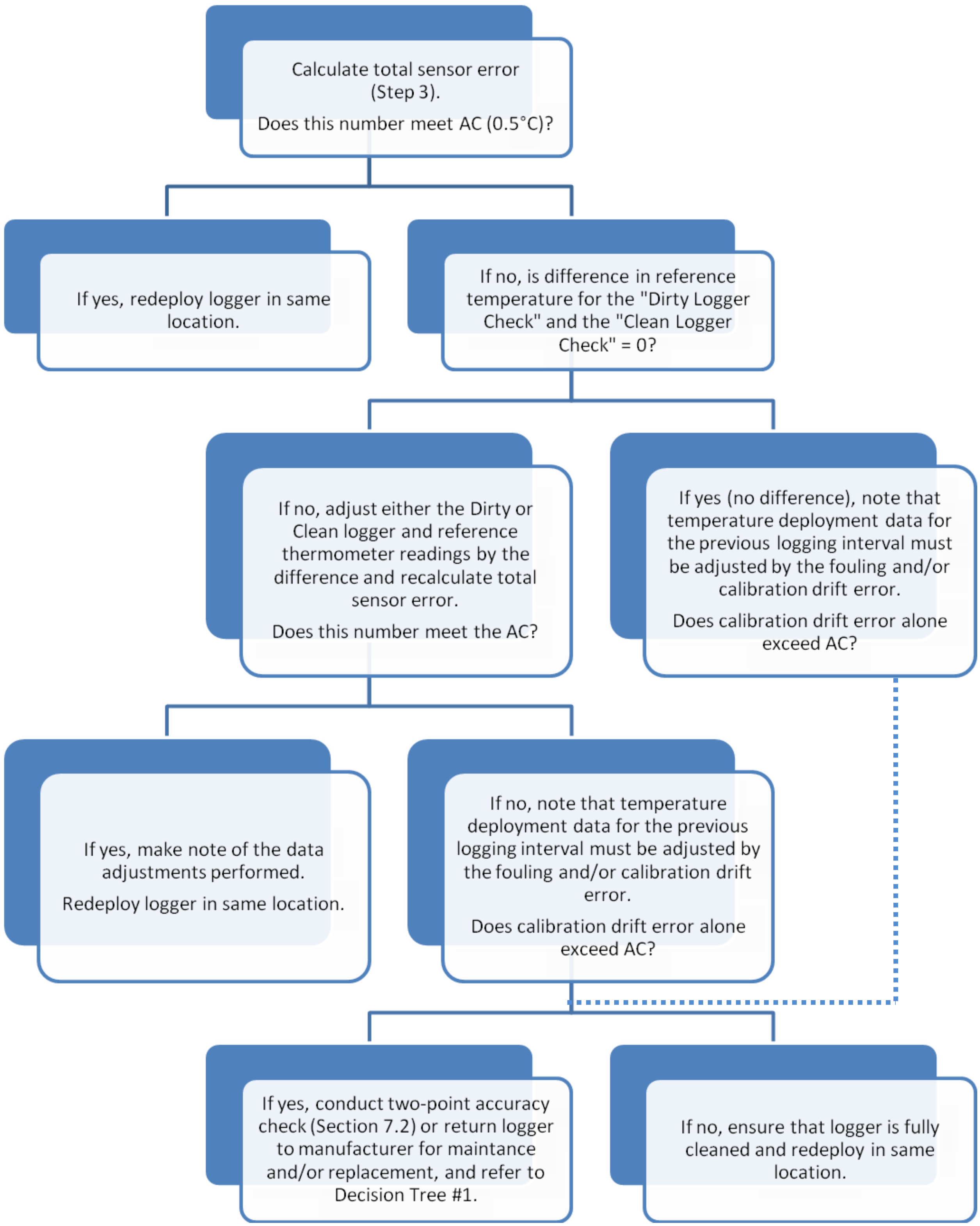
2) Accuracy checks are conducted three times per year (in January, May, and September) as described in Section 7.3 after downloading data and noting fouling and dewatered or buried conditions:



3) Calculate total sensor error:

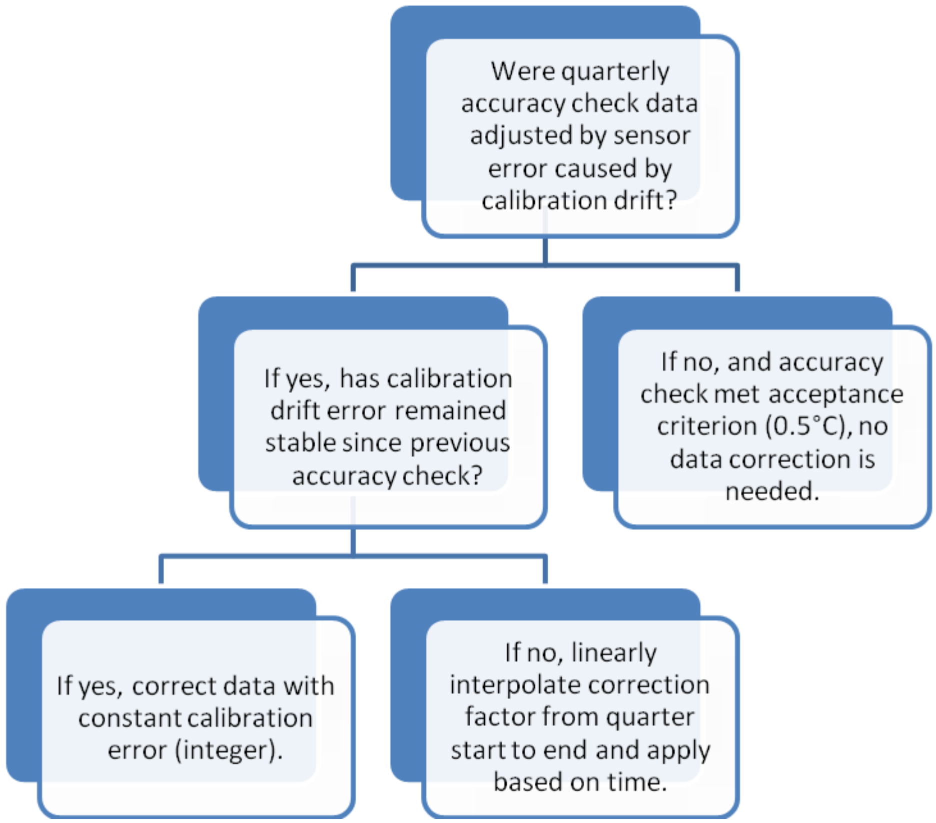


4) Does total sensor error meet acceptance criterion (≤0.5°C) (Section 7.5)?



5) Decide whether data need to be corrected

   a. Do you need to correct data for sensor error caused by calibration drift?



b. Do you need to correct for sensor error caused by fouling?