Water Temperature Monitoring

Restoration Monitoring Guidance

10 April 2025

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CONTENTS

Acronyms and Abbreviations

CTD	Cumulative Temperature Distribution
MWAT	Maximum Weekly Average Temperature
MWMT	Maximum Weekly Maximum Temperature
NIST	National Institute of Standards and Technology
QAQC	Quality Assurance and Quality Control

1. OVERVIEW

Water temperature is a key driver of ecosystem processes in streams and is an important parameter which determines many aquatic habitat attributes and the general health of river ecosystems (Caissie 2006). Measuring stream temperature can allow restoration practitioners to identify locations that would benefit from restoration actions, to better understand how and why temperatures change over time or at different locations, and to anticipate the consequences of these changes.

The primary purpose of this document is to provide guidance on how to collect accurate, continuous water temperature data at wadeable stream sites using inexpensive, readily available equipment. The sections below outline equipment requirements, sensor configuration and placement, deployment techniques, data retrieval, and data processing for measuring continuous water temperature.

Although this document focuses on measurement of temperature using continuous data loggers deployed at discrete locations within the water column, the content may be useful for adaption to other water temperature monitoring approaches such as intragravel (e.g., Zimmerman and Finn 2012), and hyporheic/floodplain monitoring (e.g., Hester *et al.* 2009), or longitudinal temperature profiling (e.g., Vaccaro and Maloy 2006, Selker *et al*. 2006).

1.1 Study Design Considerations for Reach-Scale Restoration

When designing a temperature monitoring program for reach-scale restoration, it is important to clearly identify the program objectives. Objectives of temperature monitoring studies may include assessing stream reaches of importance for specific fish species and/or life stages, or determining the stream temperature response to a specific restoration activity. The section below provides guidance on how to frame specific study objectives and questions of interest and is adapted from Heck et al. (2018) and Schuett-Hames et al. (1999).

If the monitoring objective is to assess and monitor stream temperatures in reaches of importance to specific fish species and/or life stages, then it is important to first identify those stream reaches of interest (e.g., areas used for summer rearing or reaches used for adult migration and holding during the summer or early fall). If many reaches are identified, it may be necessary to sample the most important reaches, or stratify them on the basis of channel morphology (gradient, confinement, channel width, or geomorphology), riparian condition (species, age, adjacent land-use), and other factors that affect temperature regimes (elevation, lakes, wetlands) and sub-sample each stratum.

If the monitoring objective is to test the effects of a restoration activity (e.g., riparian planting, floodplain reconnection) on the temperature regime of a stream reach, one approach might involve comparing stream reaches affected by the ‘treatment’ with similar, control (remaining degraded) or reference (best attainable condition) stream reaches. A before/after, upstream/downstream, and/or paired stream reach design may be applied. Ideally a BACI (before-after-control-impact) approach will be taken, which is able to control for both spatial and temporal variation.

- The before/after approach requires monitoring of the affected stream reach both before and after treatment. This design requires the assumption that climatic variability is inconsequential to stream temperature conditions. Year to year variation and underlying trends in regional summer weather and air temperature would invalidate this assumption of year to year comparability. The same rationale applies to variability in flows – whether a result of climatic (e.g., ice-pack, rainfall) or anthropogenic (e.g., water withdrawals, landscape modifications) causes – although it is possible to statistically control for flow variation if pairing temperature and discharge data. Because of the array of temporal sources of variability, multiple years of before and after data are required to ascribe observed temperature changes to the restoration activity with reasonable confidence.
- The upstream/downstream design involves sampling at two stations, one at the lower end of the affected stream reach and another above the treated area. The temperature regimes at the two stations are compared using the upstream reach as the control to determine if the temperature

changed as a result of the restoration activity. This approach controls for the temporal sources of variability associated with a before/after approach, but if an upstream/downstream design does not include data from before restoration occurred, observed differences in temperature cannot be ascribed to the restoration action (e.g., could be attributable to a pre-existing hyporheic upwelling).

- The paired stream reach design utilises one or more similar but distinct reaches as either a control or a reference site. The control/reference and treatment reach must be of similar geomorphology, elevation, drainage area and discharge, so that differences in temperature between the two reaches can be attributed to the treatment effect. Significant differences between the control and treated reach would invalidate this assumption.
- The BACI approach combines before/after and paired (or upstream/downstream) approaches, such that it isolates the effects of the restoration action from background variability. For example, temperature changes after restoration that are observed at the treatment site but not observed at the control site can be attributed to the restoration action (i.e., they are not broad-scale climatic effects, nor were they pre-existing differences between the sites). This approach still relies on the selection of appropriate control/reference sites as comparisons, and may benefit from collecting discharge data if the sites being compared are in different watersheds.

Once the monitoring reaches have been identified, a suitable location to establish monitoring stations within each reach must be selected. The most suitable location depends on the objectives of the restoration project. For example, the restoration may intend to reduce temperature gain as water flows through the restored reach, may intend to create lower temperature refuges within the restored reach, or may intend to restore floodplain connection to better moderate temperatures both within and downstream of the restored reach. In monitoring temperature, it is important to establish whether we want to obtain temperature representative of a reach (selecting a well-mixed location such as the thalweg at the head of a pool or the upstream outside edge of a meander), of a particular habitat feature (e.g., a restored summer-rearing or holding pool), or spanning multiple locations (e.g., to characterise temperature heterogeneity across a restored cross-section).

It is important to consider what aspects of thermal regimes are of most interest when designing a monitoring program. Common metrics used to describe variations in water temperature over time include: magnitude, frequency, duration, timing, and rates of change of temperatures (Arismendi et al. 2013, Maheu et al. 2015; Table 1). Note that one of the more common metrics reported in Canada and the US is MWMT, and is referred to as either *Mean* (e.g. British Columbia Ministry of Environment and Climate Change Strategy 2024) or *Maximum* (e.g., Heck et al. 2018) Weekly Maximum Temperature, though the calculations are the same. For cold-water species such as salmon, the MWMT is generally favoured over the maximum weekly average temperature (MWAT) and point maximum data, as the MWMT better reflects sustained peaks in high temperature.

The temperature metrics for a restoration project can be compared to control sites, reference sites, and/or biological benchmarks. While there exists considerable information regarding the optimal temperature ranges for particular species and life stages, it remains possible that the locally-adapted population at the restoration location may not align with published optima. As such, benchmarks provide useful guidance, but should not be considered absolute indicators of success or failure.

It is important to note that, when presented with a variety of potential metrics, the metrics should be chosen before data is analysed (akin to *a priori* hypotheses and predictions).Otherwise, there is a risk of 'data dredging' – comparing multiple metrics and choosing the ones that best support our expectations. We recommend that MWMT is reported as standard, and that any frequency or duration metrics are based on the best available biologically meaningful thresholds for the species, life stage, and geographical location.

Table 1: Categories of Temperature Descriptors (Adapted from: Heck et al. 2018)

Category	Description	Descriptor	Definition
Magnitude (°C)	Magnitude refers to how warm or cold temperatures are. Understanding magnitude can be important for addressing questions about water quality.	Maximum	Warmest temperature (typically of the year)
		MWMT	Maximum Weekly Maximum Temperature[1]
		MWAT	Maximum Weekly Average Temperature[2]
		Degree days	Accumulation of temperatures over time[3]
Variability (°C)	Variability refers to temporal fluctuations in temperature across a given time period. Although stream fishes have adapted to withstand temperatures fluctuating on a daily basis, the magnitude of that fluctuation must remain within their range of biological tolerances.	Mean range	Difference between the highest and lowest daily mean
		Max range	Difference between the highest and lowest maximum
		Mean Variance	A statistical measure of deviations among daily means
		Max Variance	A statistical measure of deviations among daily maximums
Frequency (n)	Frequency refers to how many times a given thermal condition is observed. For example, there may be an interest in how many times water temperatures exceeded thresholds that might cause biological stress for given fish species or other aquatic organisms.	Days > 16 °C	Number of days in the record that exceeded 16 °C
		Days > 18 °C	Number of days in the record that exceeded 18 °C
		Days > 20 °C	Number of days in the record that exceeded 20 °C
Duration (n)	Duration refers to how long a given thermal condition persists. For example, studies of cold-adapted stream fish (such as trout) shows that thermal tolerance is a function of temperature (magnitude) and its persistence (duration, expressed as the number of days that temperatures exceed a critical threshold; Wehrly et al. 2007).	Consec. Days > 16 °C	Consecutive number of days in the record that exceeded 16 °C
		Consec. Days > 18 °C	Consecutive number of days in the record that exceeded 18 °C
		Consec. Days > 20 °C	Consecutive number of days in the record that exceeded 20 °C
Timing	Timing of temperatures may influence the onset of different portions of the life cycle of aquatic organisms (for example, spawning, hatching, migration) or seasonality of factors with major ecosystem consequences (such as onset of algal blooms).	CTD[5] 50%	Date of attaining 50% of the degree days in a given time frame[4]
		CTD 75%	Same as above, but for 75% of the distribution
		Accumulated Thermal Units (ATU)	1 ATU is equal to 1 degree Celsius for 1 day. The ATU is the sum of daily mean temperature above 0 °C corresponding to the time from fertilization to emergence from the gravel/set benchmark

Notes:

[1] *Highest 7-day mean of maximum daily temperatures in any season or year. Also referred to as 'mean weekly maximum temperature', 'temperature maximum moving average (7-Day'), '7-day daily maximum temperature (7-DADMax)', etc.*

[2] *Highest 7-day mean of average (mean) daily temperatures in any season or year.*

[3] *Can be calculated by adding up mean temperature for each day greater than zero degrees.*

[4] *Summing degree days provides a tally of cumulative temperatures. Fifty percent is the point at which one-half of the total heat has accumulated within a time frame (for example, within a year).*

[5] *CTD = Cumulative Temperature Distribution.*

2. EQUIPMENT

This document provides guidance for continuous temperature measurement using in-situ loggers that remain in the location they are deployed. A number of alternative approaches exist, such as drone-based infrared for obtaining surface temperature data across broader spatial scales, distributed temperature sensing (fiber-optic cables) for longitudinal temperature profiles, or use of handheld thermometers. Depending on the restoration objectives, it may be appropriate to supplement continuous temperature data with spatial context. For example, in a floodplain restoration project, it may be beneficial to obtain cross-sectional temperature profiles at surface and at depth when visiting the site.

The following components are needed to collect and access continuous temperature measurements.

- Temperature sensor
- Data offload device compatible with the model of the sensor
- Laptop with software that is compatible with the data offload device
- Sensor housing (i.e., radiation shield) to prevent direct solar radiation from hitting the sensor and protect it from debris

Refer to Appendix A for a detailed site visit checklist. When purchasing equipment, ensure that the data offload device and software are compatible with the model of the temperature sensor. Buying the same model is often the most cost-effective option as only one data offload device and one software package are required for that particular model of sensor.

2.1 Choosing a Temperature Sensor

The following features should be considered when selecting a temperature sensor for use in monitoring programs:

- Accuracy (i.e., how close the temperature measurement is to its 'true' value)
  - Minimum of ± 0.5ºC.
  - Accuracy checks can be performed to make sure the sensor meets the appropriate specifications (Section 3.1).
- Resolution (i.e., the smallest detectable increment that the sensor can measure)
  - Must be less than the accuracy (i.e., < 0.5ºC).
- Measurement range
  - Sufficient to capture the full range of expected temperatures.
- Memory capacity
  - Sufficient to record measurements at regular, pre-programmed intervals (generally 1 hour, 30 minute, or 15 minute intervals) throughout the deployment period. The sampling interval selected will depend on the intended duration of deployment, memory size of the temperature data logger, as well as daily variability and range of temperature at the monitoring sites (Dunham et al. 2005).

When comparing restoration sites to control or reference sites, and when comparing data over years, it is important that the sampling interval remains consistent. Additionally, for comparisons with other types of data, it is recommended that the same sampling interval is used for all deployed instrumentation (e.g., air temperature sensors, pressure transducers etc.).

- Durability
  - Capable of withstanding multiple years of use in challenging conditions. Sensors should be waterproof.
- Battery life
  - Sufficient to power the sensor throughout the deployment period.
  - If sensors with non-replaceable batteries are used, document the sensor’s use so you know when to replace the sensor.
- Programmability
  - Capable of programming a start time and date.

Note, the same sensors used to measure water temperature can be used to measure air temperature (as study design requires) provided they capture the full range of air temperatures that are expected to occur throughout the deployment period.

2.2 Choosing a Portable Data Offload Device

A portable data offload device (sometimes called a base station) is a component supplied by the sensor manufacturer and is designed to facilitate data retrieval. One example is shown in Figure 1. In this example, a coupler (specific to the sensor model) is attached to the sensor, which is then connected to the base station. The base station is then connected to a computer with the appropriate software installed (specific to the manufacturer) to download and view the data.

Figure 1: Schematic illustrating the data retrieval process for an Onset TidbiT © v2 sensor (Source: USEPA 2014; Onset Computer Corporation n.d.-a)

Some manufacturers make small, portable waterproof devices (often called shuttles) that can offload data while the sensor remains in the stream. These devices can both temporarily store data from multiple sensors and serve as a base station, but are typically more expensive than non-waterproof base stations. Given that sensors are likely to be housed in radiation shields throughout the deployment period, and the sensors must be removed from these shields before they can be attached to the data offload device, the main benefits of the waterproof shuttles are that they can be used to offload data in inclement weather and in instances where bringing a laptop may be impractical (i.e., at remote sites).

2.3 Choosing Radiation Shields

All temperature sensors should be housed in some form of radiation shield, so that sunlight striking the sensors will not bias temperature readings (USEPA 2014, Isaak and Horan 2011). These housings also serve to protect the sensor from moving debris and provide secure attachment points.

Radiation shields can be purchased from a manufacturer or constructed from materials available at a local hardware store (e.g., 1.5 inch (inside diameter) PVC pipe, Figure 2).

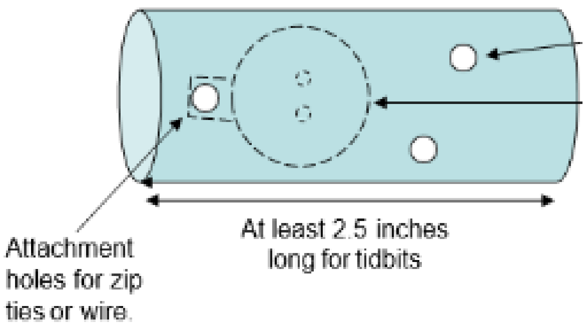

Figure 2: Example of constructed PVC housing for water temperature sensors (Source: Nelson and Dugger 2022).

One example of a more protective radiation shield that can be constructed from readily available, inexpensive material and can be used to protect water temperature sensors is shown in Figure 3 (Adapted from Mauger 2008). It consists of the following materials:

- 2” schedule 40 white polyvinyl chloride (PVC) pipe (1’ length)*
- Green spray paint (Krylon© Fusion spray paint, is formulated to bond to plastics including PVC)*
- (2) 2” DWV cleanout plug
- (2) 2” DWV female adaptor
- (1) 3/8 “ x 4” ZC eye bolt
- 8” cable ties
- PVC cement
- 3/8” nuts
- Electric Drill

*Note, white PVC in a stream is often conspicuous and can increase the risk of vandalism or tampering. To camouflage the housing, use a spray paint colour that blends in with the streambed material (Fogg et al. 2020). Black PVC housing may bias temperature measurements because they can absorb and reradiate heat (Dunham et al. 2005).

Instructions to construct the housing are as follows (sourced from Mauger 2008):

1. Using the multipurpose cement, attach the female adapter to each end of the PVC pipe.
2. Drill a 3/8” hole through the top of the cleanout plug for one eyebolt to go through.
3. Secure the eyebolt through the cleanout plug with a nut.
4. Drill at least 20 holes in the PVC pipe to allow water flow.
5. Suspend the sensor in the housing using a cable tie threaded through the drilled holes.
6. Additional cable ties can be used to secure rocks in the bottom of the housing to weigh it down (as necessary).
7. Screw the cleanout plugs into the female adapters.

Methods for securing the sensor instream are described in Section 4.2.

Radiation shields designed to house **air temperature sensors** (if using) can either be purchased from suppliers including Onset Computer Corporation and Campbell Scientific (~$80 each), or custom-built versions can be constructed (Figure 4). A custom-made radiation shield developed and tested by Holden et al. (2013) costs approximately $3.00 (USD) per shield, can be constructed in approximately 10 minutes, and uses materials widely available in hardware stores. A short video detailing its construction can be found at http://www.youtube.com/watch?v=LkVmJRsw5vs.

Figure 3: Constructed PVC housing for water temperature sensors (Source: Mauger 2008).

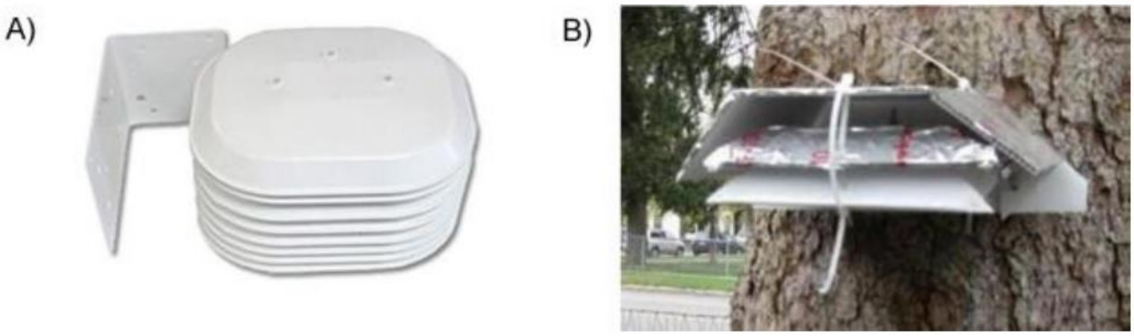

Figure 4: Examples of radiation shields for air temperature sensors (A) Gill-style Onset RS1 solar radiation shield and (B) Custom-built design by Holden et al. 2013 (Source: USEPA 2014)

3. PRE-FIELD CHECKS

3.1 Accuracy Check

Before deploying the temperature sensors in the field, complete the following checks:

- Perform either a single- or multi-point accuracy check to verify that the sensors meet the accuracy quoted by the manufacturer (Refer to instructions in Sections 3.1.1 and 3.1.2 below).
- Check the battery life and remove sensors with low battery levels.
- Ensure the sensors are launching and downloading data properly.

3.1.1 Single-Point Accuracy Check

A simple procedure for performing accuracy checks on temperature sensors is the “ice bucket” method, described below (adapted from Dunham et al. 2005, Onset Computer Corporation n.d.-b, and USEPA 2014). Note, temperature sensors that are not waterproof will need to be placed into a waterproof housing prior to testing:

1. Prepare an ice bath in a large cooler. Place crushed ice (preferably made from distilled water, as dissolved minerals can alter the thermal properties of water) in an insulated container that is large enough to hold the temperature sensors that are being tested. It is important to crush the ice to maintain as consistent and uniform a temperature as possible. Fill the container with distilled water to just below the level of the ice and stir the mixture around.
2. Allow the ice bath to sit for 2 hours to allow water temperature to stabilize.
3. Measure the temperature of the ice bath using a NIST-certified thermometer. The temperature should read 0°C.
4. Prepare the sensors by connecting them to a computer and programming them to record at 2-minute intervals.
5. Put sensors in the cooler. The sensors should be fully submerged.
6. Place the entire container in a refrigerator to minimize temperature gradients. Leave the sensors in the ice bath for a minimum of 1 hour.
7. Remove the sensors from the cooler.
8. Download the data from each sensor and plot the measurements.
9. The final sensor measurements should be within ±0.5°C of the NIST-certified thermometer readings. If the sensors are outside that range, separate them out for further testing or return them to the manufacturer for replacement.
10. Record the data on an accuracy check datasheet (Appendix A).

3.1.2 Multi-Point Accuracy Check

Alternatively, a more rigorous multi-point check can be performed as follows:

1. Prepare the sensors by connecting them to a computer and programming them to record at the same sampling intervals that will be used in the field (e.g., every 30 minutes).
2. Place the sensors in an open container and fill the container with enough water to fully submerge the sensors. Note, temperature sensors that are not waterproof will need to be placed into a waterproof housing prior to testing.
3. Put the container in an area that is at room temperature (near 20°C) for a least 4 hours.
4. As close as possible to a time when the sensor is recording a measurement, gently mix the water in the container and measure the water temperature with a NIST-certified thermometer. Record the value on an accuracy check data sheet (Appendix A).
5. Place the container with the sensors in the refrigerator (near 0°C) for at least 4 hours.
6. Remove the container from the refrigerator as close as possible to a time when the sensor is recording a measurement. Gently mix the water and measure the water temperature with a NIST thermometer. Record the value on an accuracy check data sheet.
7. Repeat steps 3 – 6 several times to create multiple warming/cooling cycles.
8. Remove the sensors from the container.

9. Download the data from each sensor and calculate the overall average temperature of each individual sensor for the entire calibration period as well as the maximum and minimums of each temperature cycle.
10. Compare the mean temperature value to the group average.
11. Compare the sensor temperature values to the NIST thermometer values (for the dates and times when measurements overlapped). Calculate the average difference between these values. Note, it should not exceed the accuracy quoted by the manufacturer of the temperature sensor. If the sensors are outside that range, separate them out for further testing or return them to the manufacturer for replacement.
12. Record all accuracy check information on a data sheet (Appendix A).

3.2 Sensor Configuration

Once accuracy checks have been completed the sensors are ready to be configured. The following practices will make data processing and screening more efficient:

- Program the sensors for a delayed start time and date that begins at least one hour before the first planned deployment time. Configure the sensors to start recording on the hour (xx:00).
- Set the units to degrees Celsius.
- Configure the time settings (24 hour clock). Consider using local standard time instead of daylight savings time. Regardless of which you choose, when doing accuracy checks, make sure any discrete measurements taken are consistent with this setting.
- Set the sensors to record point temperature measurements at a pre-determined sampling interval sufficient to capture the thermal regimes at the site (generally 1 hour, 30 minute, or 15 minute intervals). The sampling interval selected will depend on the intended duration of deployment, memory size of the temperature data logger, as well as daily variability and range of temperature at the monitoring sites (Dunham et al. 2005). To ensure data are easily comparable with other data sources, it is recommended that the same sampling interval is used for all deployed instrumentation (e.g., air temperature sensors, pressure transducers etc.). Some considerations:

  - If long intervals are used, there is potential to miss the maximum and minimum daily temperatures as they might only occur briefly within a day. In general, longer intervals (e.g., greater than 2 hours) will result in lower resolution and greater potential for bias (Dunham et al. 2005).

  - In some instances, it may be necessary to sample with high frequency (short time intervals, e.g., 30 minutes) if the variability or range in temperatures throughout the day is large (Dunham et al. 2005). However, if too short an interval is used, sensor memory could be more quickly diminished, requiring more site visits, and data management.

- If the sensors have “sensor high, low, and multiple sampling” features and “wrap-around- when-full, overwrite oldest data” functions, turn these functions off.

Sensor configuration details and deployment information should be recorded on a field sheet (Appendix A).

4. SENSOR DEPLOYMENT

4.1 Site Selection

The specific stream and reach selected for sensor deployment will depend on the objectives of the monitoring program (Section 1.1).

Once at the stream site, the following factors should be considered when establishing the deployment location for a water temperature sensor:

- Consider whether the site can be safely accessed by field teams during different flow conditions.
- If obtaining samples to characterise general reach temperature trends, locate a spot in the channel where the water is adequately mixed and not influenced by tides or localized warm or cool water sources (e.g., ground water seeps, hot springs, point-source discharges, lake outlets, tributary confluence, streamside wetland areas).
  - Well-mixed water moving into runs and pools are preferable over riffles.
  - Avoid backwater pools or standing water and do not place the sensor below a tributary stream unless that is part of the study design.
  - To confirm that the sensor deployment site is well-mixed horizontally and vertically, take at least ten measurements across the stream width with a hand-held thermometer or temperature probe, which has been calibrated in the office with a National Institute of Standards and Technology (NIST) thermometer. If field teams have access to a multi-probe meter, it is helpful to measure dissolved oxygen and conductivity as well, because variability in these measures could indicate sources of thermal variation (Dunham et al. 2005). If these measures exhibit a high degree of variability, consider moving to a different deployment location.
- Select a location that allows for the sensor to remain in sufficient water depth during periods of low flow.
  - If the sensor is deployed at high flows, crews should return to the site later in the year to confirm that the sensor remains submerged and the site is well-mixed at lower flows.
- When possible, sensors should be deployed approximately 0.15 m above the stream bottom to minimize the influence of groundwater and subsurface flow on temperature readings. In instances where this is not possible (e.g., in small, shallow streams where the sensor may be out of water during low flows if it is not deployed near the stream bottom), note this on the field form (Appendix A).
- Consider human activity in the area and select a spot that is relatively secluded to reduce the risk of vandalism/disturbance.
- Ensure the criteria used to identify the site for deployment at the restoration site are consistently applied to the control site to the greatest extent possible. For example, if monitoring rearing pool summer temperatures at the restoration site, locate the most similar habitat type at the control site.

4.2 Deployment Methods – Water Temperature Sensors

When selecting the method for deploying the water temperature sensor, field teams should consider:

- How the deployment structure will function in high and low flow conditions
- How much streambed movement is anticipated
- How to reduce tripping hazards from material used to anchor the sensor in the stream (e.g., rebar, cables etc.)
- How the deployment method will respond in ice conditions
  - Depending on monitoring objectives, crews may want to consider removing the sensor before freeze up to reduce the chance of losing the logger during spring high flows.

Four deployment methods are presented in Table 2. Alternatively, Fogg et al. 2020 present a simple, low-cost method for logger installation applicable in streams with exposed bedrock or boulders. The method they present involves using climbing hangers to affix loggers in the stream, allowing for long-term monitoring that is minimally invasive, tamper resistant, and has high logger retrieval rates after long-term deployments. This method requires the use of a cordless hammer drill and a ½ inch diameter concrete drill bit, 39 inches in length to drill a hole underwater at the attachment site (i.e., the position of the logger underwater is limited by the length of the drill bit unless a waterproof submersible hammer drill can be sourced). Refer to Fogg et al. (2020) for detailed guidance. Ultimately, site-specific conditions will dictate which installation technique is most appropriate.

Table 2: Examples of Deployment Methods for Water Temperature Sensors (Adapted from: Mauger 2008, USEPA 2014, Nelson and Dugger 2022, Jones and Allin 2010, and Heck et al. 2018)

Method Type	Photos	Site Conditions	Materials	Instructions
Rebar Method	  (Source: Mauger 2008, USEPA 2014)	Moderate movement of the streambed during high flows.	■ 1/2" rebar (4' length)* ■ 3/8 " x 4" ZC eye bolt (1) ■ 9/16 - 1 1/16 hose clamp (3) ■ 1/8" wire rope clip (2) ■ 1/8" RL uncoated cable (2' length) ■ Sledgehammer or post-pounder *If possible, use rebar that is bent (pictured on the left). This serves two purposes (1) It is anchored in two places, making it more secure and (2) no sharp points protrude upward (reduced safety risk).	■ Secure an eyebolt to the rebar (approximately 1 foot from an end) with hose clamps. ■ Secure one end of the cable to the eyebolt with a wire rope clip. ■ Secure the other end to the protective case or PVC housing using a wire rope clip. ■ Use a sledgehammer or post-pounder to sink the rebar 3 feet into the stream bottom near a large rock or other landmark.

Stream Bank-Secured Cable Method	 (Source: Mauger 2008)	Significant movement of the streambed during high flows	■ 1/8” to 3/8” diameter plastic-coated wire rope (12’ length) ■ Wire rope clips	■ Secure the protective case or PVC housing to the wire rope using a wire rope clip. ■ Upon deployment, wrap the cable around a large tree, rocks, bridge supports, or other secure object within the stream or on the stream bank. Use wire clips to secure the cable around the structure. ■ Place the logger within the stream channel and cover the cable with large rocks to hold the logger in place and conceal the cable.
Existing Stable Instream Structure (e.g., large woody debris, roots, large boulders)	 (Source: USEPA 2014)	Presence of stable instream structures that are located in or extend into the desired deployment location	■ Heavy duty (e.g., 120-lb tensile strength) cable ties and/or wire ■ Cable or heavy duty wire (as needed)	■ Attach the water-temperature sensor (in PVC housing) to these structures with cable ties or wire, or to cable or heavy wire that may be used to create the location near the base of these structures. ■ If site conditions permit, attach the sensors to the downstream side of the instream structure, as this will shield the sensor from moving rocks or debris during floods. ■ If you think the structure might move during high flow events, consider cabling or chaining the structure to an object on the nearest bank (or to another stable instream structure)

Heavy Weight (e.g., concrete block, sand bag filled with rocks)	 (Source: Jones and Allin 2010)	Minimal movement of the streambed during high flow events Presence of near-surface bedrock or other consolidated sediments that prohibit rebar use Note: this is not considered a viable option in locations with significant groundwater inflow.	■ Heavy weight (e.g., concrete block, sand bag filled with rocks on-site) ■ Heavy duty (e.g., 120-lb tensile strength) cable ties and/or wire ■ Cable or heavy duty wire (as needed)	■ Attach the water temperature sensor to a heavy weight that may be set in the desired location. ■ Cable the heavy object to something on the nearest bank (or other stable instream structure) to prevent loss during a possible high flow event.

4.3 Deployment Methods – Air Temperature Sensors

Pairing air temperature measurements with concurrent water temperature measurements can provide information about the responsiveness of stream temperatures to air temperatures and the differing vulnerabilities of streams to thermal change. Air temperature data can also be used for quality assurance and quality control (QAQC) procedures. For instance, a close correspondence between water and air temperature can indicate the water temperature sensor is out of the water.

Depending on study objectives and site conditions, it may be sufficient to compile air temperature observations from the nearest active weather station. Note that, how well the weather station data approximate on-site conditions depends on factors including the distance between the site and weather station, differences in topography, and weather patterns.

If the site conditions and/or study design requires that an air temperature sensor is deployed in conjunction with the water temperature sensor(s), the deployment method is as follows:

If the riparian zone is forested, mount the air temperature sensor to the tree that is (1) closest to the water temperature sensor and (2) large enough to support the radiation shield and sensor (ideally a tree > 0.4 m in diameter). A coniferous tree that does not lose its leaves in winter is preferred. Attach the radiation shield and sensor to the north side of the tree, out of direct sunlight, and approximately 2 metres off the ground. Note, the location of the air temperature sensor in relation to the water temperature sensor must remain constant throughout the period of data collection.

4.4 Documentation

Thoroughly documenting sensor placement is a critical part of the deployment process. Guidelines for documenting sensor installation are listed below. Field forms are provided in Appendix A.

1. Record global positioning system (GPS) coordinates (latitude and longitude) for the exact site at which each sensor is deployed, as well as the datum of the GPS.
2. Take photographs from different perspectives (i.e., view facing upstream, downstream and from each side of the channel). At least one photo should have a visual marker (e.g., someone pointing to the location of the temperature sensor). Annotate the photos with notes including landmark references, sensor locations, direction of stream flow, site access, and any other relevant details.
3. Draw a detailed site map with landmark references (e.g., unique rock, log, root, tree, or flagging), sensor locations, direction of stream flow, access route.
4. Take instantaneous temperature measurements at the locations of the sensors with a NIST-calibrated field thermometer. This should be taken as close as possible to the time when the sensor will be recording a reading. This measurement will be used as an accuracy check.
5. At the location of the water temperature sensor, measure and record the total water depth, distance from the logger to the streambed, and distance from the water surface to the logger.
6. Consider whether or not to use signage at the site, though be aware that this could increase the chance of vandalism.

5. SENSOR MAINTENANCE AND MID-DEPLOYMENT CHECKS

If possible, try to revisit the site within the first month after the equipment is installed to confirm that the installation is stable and the sensor is fully submerged. After this point, the sites should be visited as frequently as the field schedule allows to check the condition of the sensors, collect data for mid-deployment accuracy checks and download sensor data.

If possible, bring a laptop (with appropriate software) and base station or waterproof shuttle to download sensor data. This allows field crews to:

- Screen the data for atypical results. If readings are unusual, consider replacing the sensor or moving it to a different location (e.g., in instances where the sensor is not submerged)
- Check the battery life and memory capacity

The step-by-step procedure for sensor maintenance, accuracy checks and data download is described below:

1. Check the condition/stability of the sensor housing and deployment equipment and make any necessary adjustments. Look for signs of physical damage, vandalism, or disturbance.
2. Check that the sensor is submerged. If deemed appropriate based on the established study design, move it to a location that allows for the sensor to remain in sufficient water depth during periods of low flow. Document this on the field form (Appendix A).
3. Check that the sensor is not buried in sediment. If necessary, remove the sediment and reinstall the sensor in a location where it is not likely to be buried during future high flow events. Document this on the field form. Temperature recordings from buried sensors are likely to be biased toward cooler temperatures by hyporheic flows.
4. Check whether the sensor/protective housing needs to be cleaned to remove biofouling, debris, or aquatic vegetation. Make sure to record a note in the field form indicating the time at which the ‘pre-cleaning’ measurement was made and the time of the first ‘post-cleaning’ measurement. Compare the readings.
5. Take at least ten measurements across the stream width with a hand-held thermometer or temperature probe, which has been calibrated in the office with a National Institute of Standards and Technology (NIST) thermometer. If field teams have access to a multi-probe meter, it is helpful to measure dissolved oxygen and conductivity as well, because variability in these measures could indicate sources of thermal variation (Dunham et al. 2005).
6. Take photos to document any changes to the monitoring location.
7. Take instantaneous temperature measurements at the locations of the temperature sensors with a NIST-calibrated field thermometer. This should be taken as close as possible to the time when the sensor will be recording a reading.
8. Download sensor data:

    a. Wipe the sensor with a soft wet cloth or soft bristled brush to remove any biofilm or sediment that could affect its ability to connect.

    b. Attach the sensor to a base station or shuttle and then connect the data offload device to a laptop (with the appropriate software installed).

    c. Once the connection is established, follow the manufacturer’s guidance to complete the data download.

    d. Back up the data onto a flash drive.

    e. If necessary, clear the sensor memory to ensure sufficient capacity for continued deployment.

9. If the sensor is functioning properly and has sufficient battery life, it can be redeployed at the site.
10. If removing a sensor from a site, mark it with a temporary tag (e.g., flagging tape) identifying the site, date, and time of retrieval and replace the sensor with one that has passed a pre-deployment accuracy check (Section 3.1).
11. When re-deploying the sensor, aim to place it as close to the original deployment location as possible to minimize potential sources of variability in the long-term record.

12. Record site visit notes in field form (Appendix A).
13. Compare the instantaneous NIST-calibrated field thermometer measurements from the mid-deployment checks to the corresponding sensor readings. The sensor readings should not exceed the accuracy quoted by the manufacturer. If a sensor fails this check, repeat the procedure. If it fails a second time, flag the data and review the field notes for comments relating to situations that could contribute to inaccuracies in the NIST-calibrated field thermometer measurement (e.g., instances where the measurement could not be taken in close proximity to the sensor due to flow conditions, or used inconsistent time zones). If no issues with the NIST-calibrated field thermometer measurement are detected, consider replacing the sensor.

6. SENSOR RETRIEVAL

1. Document the condition of the site and the sensor/deployment structure
2. Record the date, time and take instantaneous temperature measurements at the locations of the sensors with a NIST-calibrated field thermometer. This should be taken as close as possible to the time when the sensor will be recording a reading. This measurement will be used as an accuracy check.
3. Take at least ten measurements across the stream width with a hand-held thermometer or temperature probe, which has been calibrated in the office with a National Institute of Standards and Technology (NIST) thermometer. If field teams have access to a multi-probe meter, it is helpful to measure dissolved oxygen and conductivity as well, because variability in these measures could indicate sources of thermal variation (Dunham et al. 2005).
4. At the location of the water temperature sensor, measure and record the total water depth, distance from the logger to the streambed, and distance from the water surface to the logger. Note any differences between the result and what was recorded during the initial deployment.
5. Remove all equipment from the site including rebar, cable, sandbags etc.
6. Once back in the office, conduct a post-deployment accuracy check for each sensor using the pre-deployment accuracy check procedure described in Section 3.1.

7. POST-RETRIEVAL QAQC PROCEDURES

Quality Assurance and Quality Control (QAQC) is essential to collecting accurate continuous temperature data. The section below outlines a standard set of procedures that should be performed to verify the quality of the data and to check for potential errors (based on guidance from Dunham et al. 2005, Sowder and Steel 2012, and USEPA 2014).

Record Keeping and Data Storage

- **Set up a robust record keeping and data storage system**. Large amounts of data will accumulate quickly, so it is important to develop and maintain a central database.
- **All field forms should be organized**, accessible and archived in a way that allows for safe, long-term storage.
- **Original raw data files should be retained** for all sites and should be kept separate from files in which data have been manipulated.
- **Carefully document any changes** that are made to the data. The checks can be conducted using a number of different software packages (e.g., Microsoft Excel, Hoboware, Aquarius). Both the original and the “cleaned” data files should be maintained and backed up.

Data Evaluation

1. Save the file that you are manipulating with a **different file name** so that it is not confused with the original raw data file.
2. Format the data so that it is easy to work with.
3. Trim data (as necessary) to remove measurement taken before and after the sensor is correctly deployed. This can be done via a visual inspection of data and by referencing field notes indicating the exact times of deployment and recovery. While reviewing the field notes, also look for comments about situations that could cause the sensor to record questionable readings (e.g., during a mid-deployment check, the sensor was found to be buried in the sand) and flag those data accordingly.
4. **Visual Checks** –

   a. Plot individual data points versus date/time to look for missing data and abnormalities.

   b. Graphically compare stream to air temperature (if available); a close correspondence between water and air temperature is a strong indication that the stream sensor was out of the water.

   c. (Optional) Graphically compare data across sites, years and with stage data (if available)

   d. If appropriate, graphically compare with data from the nearest weather station.

   e. If discrepancies occur, use the plots to specify the time and duration of errors in the raw data files.
5. **Automated Checks** –

   a. Calculate upper and lower 5th percentiles of the data

   b. Flag data points for potential errors if they:

   i. Exceed a thermal maximum of 25ºC*

   ii. Exceed a thermal minimum of -1ºC*

   iii. Exceed a daily change of 10ºC*

   iv. Exceed the upper 5th percentile of the overall distribution

   v. Fall below the lower 5th percentile of the overall distribution

*These values should be adjusted to thermal limits appropriate for each site.

Application of Data Corrections

Erratic readings with temperature sensors can occur for a number of reasons:

- They may become dewatered during low flow conditions.
- High flow events may bury them in sediment.
- High flow events may move them.
- They may become fouled from debris, aquatic vegetation, or algae.
- Humans may cause interference.

Errors should be addressed on a case-by-case basis. In general, there are three possible actions:

1. Leave the data as is.
2. Apply the correction factor.
3. Remove the data.

Errors should be addressed on a case-by-case basis. Table 3 summarizes different types of problems that can occur with continuous temperature data and provides recommendations for addressing them. Note, corrections should not be made unless the cause(s) or error(s) can be validated or explained in the field notes or by comparison with information from nearby stations. All actions/changes should be carefully documented and both the original (raw) and cleaned data files should be maintained and archived.

Table 3: Summary of typical problems encountered with continuous temperature data and recommended actions (Source: USEPA 2014)

Problem	Recommended Action
Missing Data	Leave blank
Water temperature sensor was dewatered or buried in sediment for part of the deployment period	Use the plot to determine the period during which the problem occurred. Exclude these data from analyses.
Recorded values are off by a constant, known amount (e.g., due to a calibration error)	Adjust each recorded value by a single, constant value within the correction period.
A large amount of drift is present. It is unknown when and by how much the sensor was 'off' (when drift occurs, the difference between discrete measurements and sensor readings increases over time)	The data should be removed
Discrepancy between sensor reading and discrete measurement taken during an accuracy or fouling check	■ If the errors are smaller than the sensor accuracy quoted by the manufacturer and cannot be easily corrected (e.g., they are not off by a constant amount), leave the data as is. ■ If the sensor fails a mid-deployment accuracy check, review field notes to see if any signs of disturbance or fouling were noted, and also look for notes about the quality of the QA/QC measurement (e.g., was the measurement taken by a National Institute of Standards and Technology [NIST] traceable or calibrated reference thermometer? Did environmental conditions prevent the measurement from being taken in close proximity to the sensor?). Also check whether the same time setting was used for both the sensor and discrete measurements (daylight savings time vs. standard time). Based on this information, use your best judgment to decide which action is most appropriate (leave as is, apply correction, or remove). ■ If a sensor fails a post-retrieval accuracy check, repeat the procedure. If it fails a second time, use your best judgment to decide which action (leave as is, apply correction, or remove) is most appropriate.

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APPENDIX A: WATER TEMPERATURE FIELD FORMS

Temperature Sensor Accuracy Check Form

#	Initials	Date	Time	Temperature (°C)						
				NIST Thermometer	Sensor	Sensor	Sensor	Sensor	Sensor	Sensor
				Serial No.	Serial No.	Serial No.	Serial No.	Serial No.	Serial No.	Serial No.
1										
2										
3										
4										
5										
6										
7										
8										
9										
10										
11										
12										
13										
14										
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16										
17										
18										
19										
20										
21										
22										
23										
24										
25										
26										

Temperature Sensor Deployment Form

General Information			
Station Number:			
Waterbody Name:			
Field Team:			
Sensor Configuration			
Serial No.:		Programmed Launch Date:	
Water or Air:		Programmed Launch Time:	
Battery Type:		Expected Retrieval Date:	
Recording Interval:			
Units:			
Sensor Deployment			
Deployment Date:		GPS Coordinates for Sensor	
Deployment Time:		Longitude (dec. degrees):	
Water Depth at Sensor Location:		Latitude (dec. degrees):	
Height of Sensor (above streambed):		File names of photos:	
Depth of Sensor (below water surface):			
Installation technique:			
Weather/Comments:			
Description of location:			
Site Map (Drawn):			

Temperature Sensor Tracking Form

Task	Date	Time	Field Crew	Notes
Pre-deployment Accuracy Check				
Launch/Start				
Deployment (in position)				
Mid-deployment Accuracy Check (write down NIST-calibrated field thermometer reading, then compare this to the sensor reading)				
Data Download				
Sensor Retrieval				
Post-deployment Accuracy Check				
Comments:				

Mid-deployment/Maintenance Check Form

Date:		Station Number:	
Time:		Waterbody Name:	
Field Team:		Water Temperature Serial No.:	
Data download (Y/N):		Air Temperature Serial No.:	
Battery Life:		Photo File Names:	

Maintenance Check:
Are there any signs of physical damage, vandalism or disturbance? If yes, describe
Is the water temperature sensor dewatered? If yes, describe
Is the water temperature sensor bureid in sediment? If yes, describe
Is there evidence of fouling (i.e., debris, aquatic vegetation, algae)? If yes, describe

Accuracy Check:
NIST traceable or calibrated reference thermometer Serial No.:

Equipment	Water		Air	
	Time	Temperature	Time	Temperature
Field Thermometer				
Sensor				

Technician conducting QA/QC check:		Station Number:	
Sensor Serial No.:		Waterbody name:	
Water or Air:			

Data Trimming	**Date**	**Time**	**Technician**
Programmed launch/start			
Deployment Start (in position)			
Out of position (e.g., data download, maintenance)			
Retrieval			

Accuracy Checks	**Pass/fail**	**Notes**
Pre-deployment		
Mid-deployment		
Post-deployment		

Checklist	**Yes/No**	**Notes**
Consistent units - did you check the units to ensure that they were consistent throughout the period of deployment (should be °C)?		
Missing data - in the Notes field, describe how you addressed these data and why you think they occurred.		
Trimming data - did you remove observations that were recorded when the sensor was NOT correctly positioned?		
Graph - did you plot all individual data points and look for abnormalities?		
Graph - did you plot air and stream temperature on the same graph and look for abnormalities?		
Graph - did you plot stream temperature and water level (if available) on the same graph and look for abnormalities?		
Graph – did you graphically compare data across sites?		
Graph – did you graphically compare data from the same site across different years?		
Graph – did you graphically compare with data from the nearest active weather station?		
Flags - did you flag values if they met the conditions below? (If you used different thermal limits, cross out the values below and write what you used)		
Exceed a thermal maximum of 25°C		
Exceed a thermal 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		

Site Visit Checklist

Pre-Deployment Preparation		Personal Gear and Safety	
Determine Number of Stations		Chest waders	
Determine Deployment Equipment Needs		PFD with whistle	
Obtain or Make Deployment Equipment		Hard Hat (as necessary)	
Check Calibration of Temperature Loggers		Safety Glasses	
Plan Deployment Schedule		Reflective Safety Vest	
Program Temperature Loggers		Change of clothes	
Travel and Personnel Logistics		Rubber boots	
Transportation arrangements (boat, helicopter, truck, ATV etc.)		Long waterproof gloves	
Appropriate tansportation safety gear		Rainwear	
Accommodations		Sunscreen/hat	
Field Assistant Arrangements		Bug repellant/Bug Jacket	
Document Preparation		Warm hat and gloves	
Field Forms printed on rite in the rain paper		Bear spray and/or bear bangers	
GPS Coordinates, maps, location instructions		First Aid Kit	
Guidance documents		Throw bag/rope	
Pens/Pencils		Hatchet/axe	
Instrument Removal/Deployment		Waterproof matches or fire starter	
Programmed Temperature Logger(s)		Waterproof bag	
NIST-certified thermometer		Towel	
Hand-held thermometer or temperature probe, which has been calibrated in the office with a NIST-certified thermometer		Heat packs	
Field computer (with charged battery) and appropriate software installed			
Data offload device			
Sensor housing(s) (i.e., radiation shield(s))			
multi-probe meter (DO, conductivity); Optional		**Tools (as needed)**	
		Pocket knife/multi tool	
Other		adjustable wrench/wrench set	
Batteries (all types)		Pruning shears	
GPS (programmed with location coordinates)		Ratchet Set	
Satellite phone		Screwdriver set or multi-head screwdriver	
Cell phone		Hack Saw	
Spot Unit/InReach		Cable cutters	
Zip-ties		sledge hammer and/or post-pounder	
Duct tape		Hammer	
Camera (with charged battery)		Vice grips (small and large)	
Desicant packs (as needed)		Cordless drill with drill bits and spare battery	
Cloths for cleaning		Spare parts (screws, hose clamps etc.)	
Flagging Tape		Wire cutters	
Utility knife			
Electrical tape			
Measuring tape			