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Best Practices for Continuous Monitoring of Temperature and Flow in Wadeable Streams

National Center for Environmental Assessment
Office of Research and Development

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National Center for Environmental Assessment
Office of Research and Development
U.S. Environmental Protection Agency
Washington, DC 20460

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ABSTRACT

The United States Environmental Protection Agency (U.S. EPA) is working with its regional offices, states, tribes, river basin commissions and other entities to establish Regional Monitoring Networks (RMNs) for freshwater wadeable streams. To the extent possible, uninterrupted, biological, temperature and hydrologic data will be collected on an ongoing basis at RMN sites, which are primarily located on smaller, minimally disturbed forested streams. The primary purpose of this document is to provide guidance on how to collect accurate, year-round temperature and hydrologic data at ungaged wadeable stream sites. It addresses questions related to equipment needs, sensor configuration, sensor placement, installation techniques, data retrieval, and data processing. This guidance is intended to increase comparability of continuous temperature and hydrologic data collection at RMN sites and to ensure that the data are of sufficient quality to be used in future analyses. It also addresses challenges posed by year-round deployments. These data will be used for detecting temporal trends; providing information that will allow for a better understanding of relationships between biological, thermal, and hydrologic data; predicting and analyzing climate change impacts and quantifying natural variability.

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ABBREVIATIONS AND ACRONYMS

DRBC	Delaware River Basin Commission
DTS	distributed temperature sensing
FMU	Freshwater Monitoring Unit
GPS	global positioning system
GZF	gage height of zero flow
NIST	National Institute of Standards and Technology
PVC	polyvinyl chloride
PZF	point of zero flow
RIFLS	River Instream Flow Stewards Program
RMN	Regional Monitoring Network
QAPP	quality assurance project plan
QA/QC	quality assurance/quality control
SOP	standard operating procedures
TIR	thermal infrared
U.S. EPA	United States Environmental Protection Agency
USGS	United States Geological Survey

PREFACE

This guidance document was prepared by Tetra Tech, Inc., the Massachusetts Department of Fish and Game/Division of Ecological Restoration, the U.S. Forest Service, the Massachusetts Cooperative Fish and Wildlife Research Unit of the U.S. Geological Survey, the U.S. Environmental Protection Agency Region 3 office, and the Global Change Assessment Staff in the Air, Climate, and Energy Program at the U.S. Environmental Protection Agency. The document facilitates more uniform and effective collection of continuous temperature and stage (depth) data at ungaged sites in wadeable streams, and addresses questions related to equipment needs, sensor configuration, sensor placement, installation techniques, data retrieval, and data processing.

AUTHORS, CONTRIBUTORS, AND REVIEWERS

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EXECUTIVE SUMMARY

The United States Environmental Protection Agency (U.S. EPA) is working with its regional offices, states, tribes, river basin commissions, and other entities to establish Regional Monitoring Networks (RMNs) for freshwater wadeable streams. To date, RMNs have been established in the Northeast, Mid-Atlantic, and Southeast. Approximately 30 RMN sites are being monitored in each region. Many of these sites are located on smaller, minimally disturbed streams in forested watersheds with drainage areas less than 100 km^2. To the extent possible, uninterrupted, biological, temperature, and hydrologic data will be collected on an ongoing basis at RMN sites. Several entities already conduct annual monitoring at targeted sites through existing programs. The goal is to integrate the RMNs into such existing programs. By coordinating efforts regionally, resources can be pooled efficiently. Detailed information about the development of the RMNs, including site selection criteria, biological sampling protocols, and data usage, is compiled in a separate report.

The primary purpose of this document is to provide guidance on how to collect accurate, year-round temperature and hydrologic data at ungaged wadeable stream sites. It addresses questions related to equipment needs, sensor configuration, sensor placement, installation techniques, data retrieval, and data processing. The protocols in this report describe simple methods and reference inexpensive tools for collecting data sustainably over the long term. This guidance is intended to increase comparability of continuous temperature and hydrologic data collection at RMN sites and to ensure that the data are of sufficient quality to be used in future analyses. It also addresses challenges posed by year-round deployments. These data will be used for detecting temporal trends; providing information that will allow for a better understanding of relationships between biological, thermal, and hydrologic data; predicting and analyzing climate change impacts; and quantifying natural variability.

The section of this document on temperature describes protocols for measuring continuous water and air temperature. At least one water and air temperature sensor should be deployed at each RMN site. The air temperature data will be used to help determine if water temperature sensors are dewatered during their deployment and will also provide important insights about the responsiveness of stream temperatures to air temperatures and the differing vulnerabilities of streams to thermal change. Two installation techniques for water temperature sensors are described in this document: the underwater epoxy method and a method in which cabling is used to attach the sensor to rebar or stable instream structures.

The hydrology section describes how to install and maintain vented and unvented pressure transducers that measure continuous stage (depth). Staff gages should also be installed at RMN sites because they provide a means for checking the accuracy of the transducer data. This report also includes a brief section on how to take discharge measurements and develop stage-discharge curves. Taken alone, stage measurements yield some information about streamflow patterns, including the timing, frequency, and duration of high flows, but to better assess patterns and changes in stream hydrology, converting stage measurements into streamflow is most useful.

This document also describes how to accurately geo-reference and document the temperature sensors and pressure transducers in a way that enables field personnel to relocate them during

subsequent visits. Efforts should be made to revisit the sites within the first month of installation to confirm that the installations are holding properly. After these initial deployment checks, sites should be visited as frequently as schedules allow to check the condition of the equipment, gather data for mid-deployment accuracy checks, and offload data.

After data are offloaded, quality assurance and quality control (QA/QC) procedures are performed to verify the quality of the data and to check for potential errors. In this document, we describe a series of checks to perform on the data, including identifying and removing observations recorded before and after the equipment is correctly positioned and plotting measurements to check visually for missing data, outliers, and other abnormalities. Large amounts of data will accumulate quickly so a central database should be developed and maintained from the initial stages of monitoring. Any changes made to the data should be carefully documented, and all data forms should be organized, easily accessible, and archived in a way that allows for safe, long-term storage.

1. PURPOSE AND SCOPE

The United States Environmental Protection Agency (U.S. EPA) is working with its regional offices, states, tribes, river basin commissions and other entities to establish Regional Monitoring Networks (RMNs) at which long-term biological, thermal, and hydrologic data will be collected from freshwater wadeable streams. At this time, RMNs have been established in the Northeast, Mid-Atlantic, and Southeast, and these efforts are being expanded into other regions.

When selecting sites for the RMNs, attempts have been made to utilize and build on data already being collected by participating entities. Site selection considerations include low level of anthropogenic disturbance; long historical sampling record for biological, thermal, or hydrological data; sustainability (e.g., accessibility, partners); classification; level of protection; and expected vulnerability to climate change. Approximately 30 RMN sites are being monitored in each region. Many of these sites are located on smaller, minimally disturbed streams in forested watersheds with drainage areas less than 100 km^2.

The need for the RMNs stems from the lack of long-term, contemporaneous biological, temperature, and flow data, particularly at minimally disturbed, freshwater wadeable stream sites (Jackson and Fureder 2006, Mazor et al. 2009, Kennen et al. 2011, Isaak et al. 2012). To the extent possible, uninterrupted, biological, temperature, and hydrologic data will be collected on an ongoing basis at RMN sites. These data will be used for detecting temporal trends; providing information that will allow for a better understanding of relationships between biological, thermal, and hydrologic data; providing information about response and recovery of organisms to extreme weather events; analyzing climate change impacts (e.g., the National Climate Assessment Indicator System); testing hypotheses and predictive models related to climate change vulnerability; and quantifying natural variability. Several entities already conduct annual monitoring at targeted sites through existing programs. The goal is to integrate the RMNs into such existing programs. By coordinating efforts regionally, resources can be pooled to gain efficiencies. More detailed information about the RMNs, including site selection criteria, biological sampling protocols, and data usage, can be found in a separate report (U.S. EPA 2014).

The primary purpose of this document is to provide guidance on how to collect accurate, year-round temperature and hydrologic data at ungaged wadeable stream sites. It addresses questions related to equipment needs, sensor configuration, sensor placement, installation techniques, data retrieval, and data processing. This guidance is intended to increase comparability of continuous temperature and hydrologic data collection at RMN sites and to ensure that the data are of sufficient quality to be used in future analyses. It also addresses challenges posed by year-round deployments. Year-round monitoring of temperature and hydrology is fundamental to understanding aquatic ecology. Although more and more continuous data are being collected, many of these data are not being collected year-round. For example, considerable amounts of stream temperature data are now routinely collected using inexpensive temperature sensors, but many of the temperature measurements are made only during summer months due to logistical constraints associated with stream access, concerns that large annual floods will destroy sensor installations, and an intentional focus on the summer season because it captures a critical time period for most aquatic species' survival. Summer-only data provide a narrow view of thermal regimes in streams and misses ecologically relevant information about the date of spring onset, growing season length, overall variability, and total annual thermal units.

Flow regime (magnitude, frequency, duration, timing, and rate of change) also strongly influences stream ecology (Poff et al. 1997). The U.S. Geological Survey (USGS) has been collecting continuous hydrologic data in streams since 1889, and currently maintains over 7,000 continuous gages. The USGS stream monitoring network provides critical, long-term, high quality information about our nation's streams and rivers that can be used for planning and trend analysis (e.g., flood forecasting, water allocation, wastewater treatment, and recreation). Many USGS stream gages are located in large rivers that have multiple human uses. Most RMN sites are located on smaller, minimally disturbed forested streams with drainage areas less than 100 km^2, so only a limited number can be co-located with USGS gages. This necessitates that hydrologic data be collected independently. The collection of year-round hydrologic data from headwater and mid-order streams is important. Streams of this size are instrumental in connecting upland and riparian systems with river systems (Vannote et al. 1980). Moreover, small upland streams, which are inhabited by temperature-sensitive organisms, are likely to experience substantial impacts from climate change (Durance and Ormerod 2007) and could also serve as refugia from the extremes in temperature and flow that are projected to occur (Meyer et al. 2007).

This report is divided into two main sections: one on temperature and one on hydrology. The temperature section describes protocols for measuring continuous water and air temperature. The hydrology section discusses how to install and maintain pressure transducers and staff gages to measure continuous stage (depth), and also includes a brief section on how to make discharge measurements to develop stage-discharge curves. The protocols in this report describe simple methods and reference inexpensive tools for collecting data sustainably over the long term. Although more advanced equipment is available, such as distributed temperature sensing (DTS) (Selker et al. 2006) and thermal infrared (TIR) imagery (Torgerson et al. 2001), most RMN members lack the resources to purchase and deploy these types of advanced equipment at numerous sites for long periods of time. Thus, they are not covered in this report. Temperature and hydrologic modeling are also considered to be outside the scope of this report.

Although this document was written for the RMNs, much of the information and detail (e.g., data forms) is useful to entities that are developing quality assurance project plans (QAPPs) and standard operating procedures documents (SOPs) for measuring stream temperature and hydrologic data with pressure transducers. We recognize that entities like USGS and some monitoring programs have been early adopters of continuous sensor technology and have written their own protocols for deploying temperature sensors and pressure transducers (e.g., MDDNR no date, Danielson 2006, Wagner et al. 2006, Wilde 2006). The information in this document is not meant to replace those SOPs, but it might supplement them. This document differs from existing SOPs in that both temperature and stage (depth) information are compiled into one place, and deployment techniques specifically address challenges posed by year-round deployment. Although we attempted to make this document as comprehensive as possible, we acknowledge that certain situations might warrant an alternative methodology, procedure, or process. Future updates and improvements will be made as we receive feedback from partners who are field-testing these methodologies.

2. TEMPERATURE

This section describes protocols for measuring continuous water and air temperature. At least one water and air temperature sensor should be deployed at each RMN site. The air temperature data will be used to gain a better understanding of the relationship between air and water temperature at each RMN site. This will provide important insights about the responsiveness of stream temperatures to air temperatures and the differing vulnerabilities of streams to thermal change. The data will also be used for quality assurance and quality control (QA/QC) procedures (e.g., to help determine whether water temperature sensors are dewatered during their deployment).

The protocols described in this section are based on a review of existing temperature protocols from the Washington State Department of Ecology (Ward 2003, Bilhimer and Stohr 2009, Ward 2011), the U.S. Forest Service (Dunham et al. 2005, Isaak and Horan 2011, Sowder and Steel 2012, Isaak et al. 2013, Holden et al. 2013), Alaska (Mauger 2008), and Maryland (MDDNR, no date).

2.1. Equipment

This section describes equipment needed for collecting air and water temperature data and discusses considerations that influence equipment selection.

2.1.1. Basic components

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

- A temperature sensor
- A data offload device that is compatible with the model of the sensor
- A computer with software that is compatible with the data offload device
- A radiation shield to prevent direct solar radiation from hitting the sensor (this can also serve as a protective housing)

Additional equipment is needed to install the temperature sensors. This is discussed in more detail in Section 2.3.2.

2.1.2. Considerations when choosing temperature sensors

When selecting temperature sensors, consider factors such as durability, accuracy, resolution, measurement range, memory, and battery life. For RMN sites, select sensors that are durable (able to withstand years of use in challenging conditions), have a minimum accuracy of ±0.5°C, capture the full range of expected temperatures, have a memory that is sufficient to record measurements at 30-minute intervals during the deployment period, and have adequate battery life (Table 1). Water temperature sensors should be waterproof (e.g., IP code level 8). Sensors are available that can measure water temperature with accuracies of ±0.2°C. If resources permit, consider using these more accurate water temperature sensors at RMN sites.

Definitions of accuracy, precision, resolution, and bias

Accuracy refers to how close the temperature measurement is to its “true” value, or its “correctness.” Precision is the degree to which repeated measurements produce the same results, assuming conditions are unchanged (also referred to as variance or “tightness”). Resolution is the smallest change that the sensor can detect, or the “fineness” to which the sensor can be read. Bias refers to whether a systematic offset occurs between the measured value and the “true” value.

The lifespan of the sensor should be another consideration. Some sensors are made to last five years or longer before their batteries expire or their cases start to leak. If sensors with non-replaceable batteries are used, document the sensor’s use so you know when to remove them from circulation and budget/plan for their replacement. Perform accuracy checks (Sections 2.2.1 and 2.6.1) to ensure that sensors meet the specifications quoted by the manufacturers. If these steps are taken, any errors associated with equipment differences will be extremely small compared to the temperature variability within and among sites.

Table 1. Specifications for temperature sensors used in the RMNs

Characteristic	Water sensor	Air sensor
Submersible/waterproof	yes[1]	optional
Programmable start time and date	yes	yes
Minimum accuracy[2]	±0.5°C[3]	±0.5°C
Resolution[4]	<0.5°C	<0.5°C
Measurement range – able to capture the full range of expected temperatures	−5 to 37˚C will typically work	depending on the location, −20 to 50˚C might be necessary (a typically available range)
Memory	Sufficient to record measurements at 30-minute intervals during deployment period	
Battery life	Sufficient to remain active during deployment period	

[1] Sometimes sensors that are not waterproof are used to measure water temperature. This is done by housing them in waterproof, non-drilled PVC canisters. However, laboratory trials suggest a time lag between changes in water temperature and air temperature within a canister (Dunham et al. 2005).

[2] Accuracy varies depending on temperature range; make sure the sensor can accurately record measurements over the temperature range that you expect the sensor to commonly experience.

[3] Water temperature sensors with accuracies of ±0.2°C are currently available. Their use at RMN sites is encouraged.

[4] Resolution is the smallest detectable increment that the sensor can measure; it needs to be less than the accuracy.

If the pressure transducer that I am purchasing can measure water temperature, do I need to purchase a separate temperature sensor?

It depends. If the temperature sensor in the transducer meets the minimum accuracy of ±0.5°C and the sensor placement conditions described in Section 2.3.1 are met, deploying a separate temperature sensor is unnecessary. Having a separate temperature sensor, however, does have some advantages. For one, it can serve as a back-up if the transducer unexpectedly fails. Data from the temperature sensor can also be used for quality control checks on the transducer data.

The same sensors that are used for measuring water temperature can be used to measure air temperature provided they capture the full range of air temperatures that are expected to occur at a site (depending on the location, a range of −20˚C to 50˚C might be necessary). Less expensive, non-waterproof sensors can also be used to measure air temperature, provided the sensors are protected from the elements (see Table 2). Radiation shields, which are discussed in Section 2.1.4, can serve this purpose.

Examples of some commercially available temperature sensors are found in Table 2, and pictures of these sensors are shown in Figure 1.

Figure 1. Numerous temperature sensors are commercially available. Examples include: A) Onset Hobo© Water Temp Pro v2; B) Onset Tidbit© v2; C) Gemini Tinytag Aquatic 2; D) Thermoworks LogTag; E) MadgeTech Temp 101A; and F) Maxim Integrated Products Thermochron ibutton.

If different sites have different makes and models of temperature sensors, how much variability will this introduce?

Not much, provided the proper accuracy checks are performed to ensure that sensors meet the specifications quoted by the manufacturers. Any errors associated with equipment differences are extremely small compared to the temperature variability within and among sites.

2.1.3. Considerations when choosing portable data offload devices

A data offload device is typically a pocket-sized device called a base station that is sold by the manufacturer of a sensor. For example, the Onset sensors use a coupler specific to the model of the sensor, which must be attached to the sensor before the sensor can be connected to the base station. The base station is then connected to a computer via a cable (Figure 2). To view the data, the appropriate software must be installed on the computer.

Table 2. Examples of commercially available temperature sensors

Manufacturer (website)	Sensor model	Water-proof	Temperature range	Accuracy[1]	Resolution[1]	Battery life (typical use) and replaceability	Approximate price[2] ($)
Onset (onsetcomp.com)	Hobo© Water Temp Pro v2 (U22-001)	yes	–40° to 70°C (air); maximum sustained water = 50°C	**0.2°C** from 0° to 50°C	**0.02°C** at 25°C	6 years, factory-replaceable	123
	TidbiT© v2 Temp Sensor (UTBI-001)	yes	–20° to 70°C (air); maximum sustained water = 30°C	**0.2°C** from 0° to 50°C	**0.02°C** at 25°C	5 years, non-replaceable	133
	Hobo© U20 Water Level Logger (U20-001-04)	yes	–20° to 50°C (air)	**0.44** from 0° to 50°C	**0.10°C** at 25°C	5 years, factory-replaceable	495
Gemini (geminidataloggers.com)	Tinytag Aquatic 2 (TG-4100)	yes	–40° to 70°C	**0.5°C** from 0°C to 50°C	**0.01°C**	1 year, user-replaceable	170
Maxim Integrated Products (maximintegrated.com)	Thermochroni-button (DS1922L)	no	–40° to 85°C	**0.5°C** from –10°C to +65°C (with software correction)	**0.5°C** (8-Bit) or 0.06°C (11-Bit)	4 years, non-replaceable	35
Thermoworks (thermoworks.com)	Log Tag	no	–40° to 85°C	**0.5°C** from –20 to 40°C	**<0.1°C**	2 to 3 years, technician-replaceable	35
MadgeTech (madgetech.com)	Temp101A	no	–40° to 80°C	**0.5°C**	**0.01°C**	10 years, user-replaceable	89

[1] Accuracy and resolution over additional temperature ranges can be found on the manufacturer specification sheets.

[2] As of January 2013 and subject to change; reduced prices might be available for bulk orders.

Figure 2. Additional equipment is needed to offload data from the temperature sensors onto a computer. This figure depicts the coupler, base station, and USB cable needed to download data from the Onset Tidbit© v2 sensor (www.onsetcomp.com). A waterproof shuttle can also be used in place of the base station for on-site data offload and temporary data storage. These devices must be compatible with the make and model of the sensor.

Some manufacturers make small, portable waterproof devices (often referred to as shuttles) that can offload data while the sensor remains in the stream. These devices, which can be used to temporarily store the data and can also serve as base stations, are more expensive than the non-waterproof base stations. At RMN sites, instream data offloads are generally not possible because sensors are housed in radiation shields (Section 2.1.4) and the sensors must be removed from these shields before they can be attached to the data offload device. Thus, the main benefits of the waterproof shuttles are that, after sensors are removed from the stream, field personnel can work with them in inclement weather, and they are easy to carry in and out of remote sites where bringing a laptop is impractical.

Consider compatibility when purchasing equipment. Ensure that the data offload device and software are compatible with the model of the temperature sensor. If purchasing multiple sensors, buying the same model is often the most cost-effective because reduced prices might be available for bulk orders and only one data offload device and one software package are necessary for that particular model of sensor. The non-waterproof data offload device/base station for the Onset Tidbit© v2 Temp Sensor costs approximately $118, software costs $89–99, and the waterproof shuttle costs $237 (these represent approximate prices on the Onset website [http://www.onsetcomp.com/] as of June 2013).

2.1.4. Considerations when choosing radiation shields

Temperature sensors should be outfitted with radiation shields so that sunlight striking the sensors will not bias temperature readings (Figure 3) (Dunham et al. 2005, Isaak and Horan 2011). These shields can also serve as protective housings and provide secure attachment points for the temperature sensors. Radiation shields can be purchased from a manufacturer or constructed less expensively from materials purchased at a local hardware store.

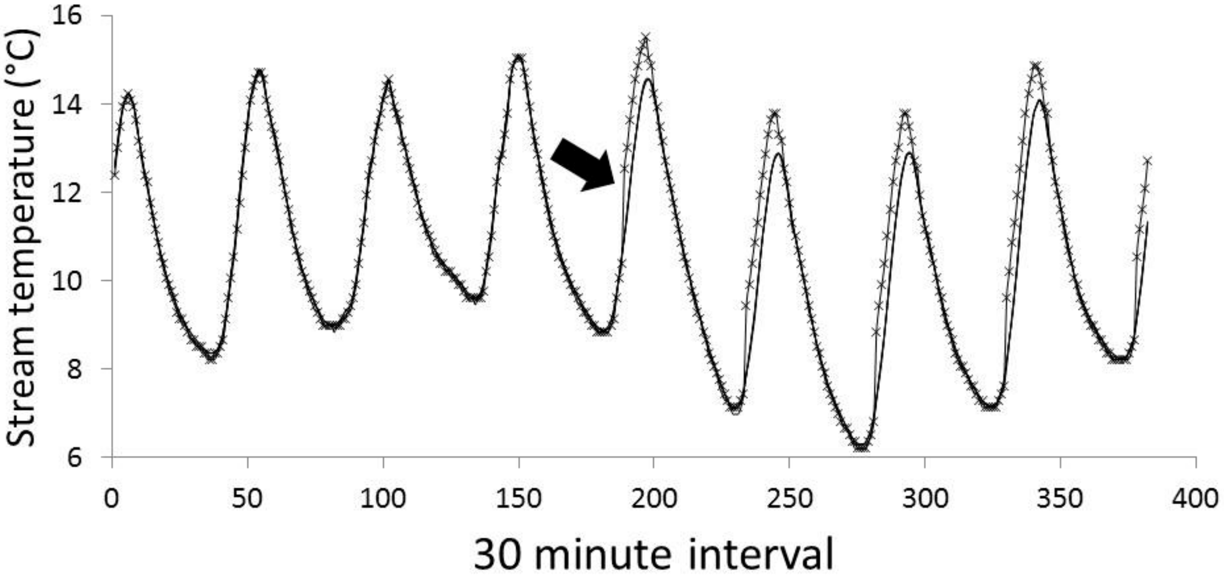


Figure 3. Stream temperature measurements from four sensors at the same site during eight days in July 2010. All sensors had solar shields during the first four days when temperature measurements overlap. The solar shield was removed from one sensor on day 5 (black arrow) and temperature spikes became apparent when sunlight struck the sensor (reproduced from Isaak and Horan 2011).

As an example, a polyvinyl chloride (PVC) canister, which is simple and inexpensive to construct, can be used to shield the water temperature sensors. The one shown in Figure 4 consists of two pieces, including a flat, solid bottom and a screw-top cap. Several holes are drilled into the canister to make it neutrally buoyant and to facilitate water circulation. The threads are wrapped with Teflon tape, and then a small piece of neoprene is zip-tied to the temperature sensor to hold it inside the cap (Isaak et al. 2013). If using the underwater epoxy installation method (described in Section 2.3.2), the PVC canister must have a lip at the bottom around which the epoxy can be wrapped or else the epoxy will not hold the PVC to the rock. More details on how to construct PVC canister shields, including specific part numbers, can be found in Isaak et al. (2013). An alternative method for constructing PVC canisters is described in Appendix A (Mauger 2008).

Does the color of the radiation shield matter?

Clear shields have been shown to cause erroneously high readings (Dunham et al. 2005). For opaque shields, there is no evidence that color affects temperature readings, likely because the shield comes in minimal contact with the sensor and flowing water removes effects of heat conduction.

Color does, however, affect visibility. White shields facilitate sensor retrieval because they are easily seen but their increased visibility could also increase vandalism rates, especially in heavily trafficked areas. If vandalism is a concern, use radiation shields that are neutral in color or paint them to reduce their visibility.

Figure 4. Unassembled components of an inexpensive PVC canister radiation shield for water temperature sensors (described in more detail in Isaak et al. 2013).

For air temperature sensors, the most effective radiation shields are mechanically aspirated, with a small fan located within the shield that maintains air flow through the shield in low wind conditions. Because these devices require power, passive/non-aspirated designs are more suitable for remote deployment.

A wide range of passive radiation shields are commercially available, and their effectiveness varies with the type or brand of funnel. The standard shield used in most weather/climate stations is called a Gill radiation shield (Gill 1979). This shield is a series of plates that reflect incoming radiation and passively radiate accumulated heat via conduction (see Figure 5A). In areas with persistent winter and spring snowpack, the radiation shield should block incident radiation not just from above, but also from below, because radiation reflecting off the snow can directly strike sensors and bias temperature readings (Holden et al. 2013).

Commercially available, passive shields (e.g., Decagon Devices Inc., Campell Scientific, Onset Inc.) can be purchased for approximately $50–80 each. The custom-made version developed by Zachary Holden (Appendix B; Figure 5B) costs approximately $2.50–3.00 per shield. Holden tested his design and found that it performed well compared to commercially available shields (Holden et al. 2013). A YouTube video (accessed 15 June 2013) with instructions on how to construct the custom-made shield can be found at: www.youtube.com/watch?v=LkVmJRsw5vs.

Other designs for air temperature shields are also available. For example, some entities use a modified version of the PVC canister shown in Figure 4. The modified version differs in that it has larger, more numerous holes. When selecting a design, consider whether the performance of the shield has been tested and documented (e.g., compared against “known” validation temperature records to determine error rates).

2.2. Pre-Deployment

2.2.1. Accuracy check

Before deploying the temperature sensors in the field, perform an accuracy check to verify that the sensors meet the accuracy quoted by the manufacturer. Also check the battery life and make sure the sensors are launching and downloading data properly. Temperature sensors with low battery levels should be removed from circulation.

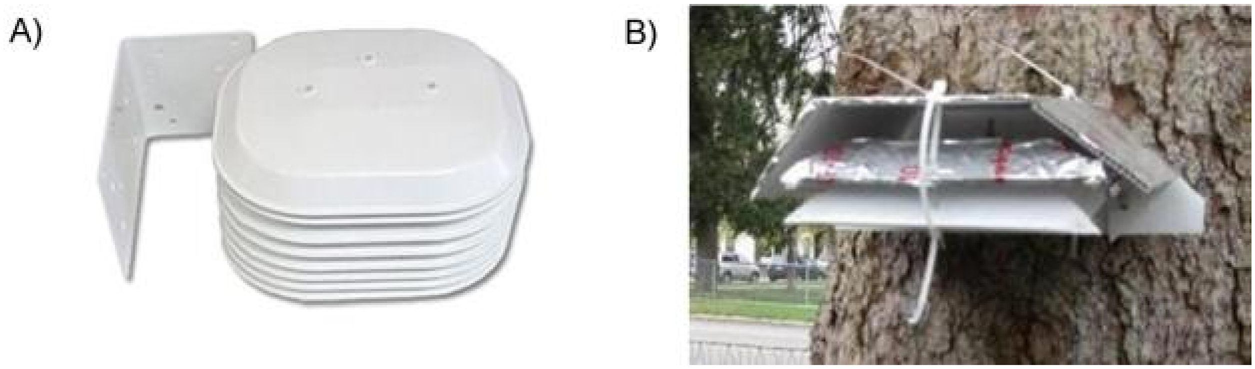


Figure 5. Examples of radiation shields for air temperature sensors include A) the Gill-style Onset RS1 solar radiation shield (www.onsetcomp.com) and B) custom design by Zachary Holden (Appendix B).

Perform either a single- or multi-point accuracy check. A simple and effective procedure for performing single-point accuracy checks on water temperature sensors is the “ice bucket” method, in which sensors are placed in an ice bath for several hours and sensor readings are checked against readings from a National Institute of Standards and Technology (NIST)-certified thermometer. Table 3 contains step-by-step procedures for the “ice bucket” method that the Maryland Department of Natural Resources (MDDNR, no date) uses. Similar techniques are described in Onset Computer Corporation (2014) and Dunham et al. (2005).

Table 3. The “ice bucket” method can be used for single-point pre-deployment accuracy checks (MDDNR, no date)

Task	Procedure
Setup	1. Prepare an ice bath in a large cooler (e.g., 48 quart). Fill the cooler half full with water and add 10 lbs. of ice. Be sure to use fresh water (dissolved minerals can alter the thermal properties of water). Place an air stone in the bottom of the ice bath to ensure mixing of the water. 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.
Test	5. Put sensors in the cooler (sensor side down). The sensors should be fully submerged. 6. Leave the sensors in the ice bath for a minimum of 1 hour. 7. Remove the sensors from the cooler.
Accuracy check	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. 10. Record the data on an accuracy check datasheet (see example in Appendix C).

The multi-point check, which is described in Table 4, is more rigorous. First, sensors are set up to record at the same sampling intervals that will be used in the field (e.g., every 30 minutes at RMN sites). Next, the sensors are exposed to alternating warm and cold cycles that approximate the temperatures and duration of diurnal fluxes to which the sensors will be exposed in the field. At various points during this process, temperature measurements are taken with a NIST-certified thermometer. After the sensors complete these cycles, the data are downloaded onto a computer and values from the sensors are checked against: 1) readings that are taken with the NIST-certified thermometer; and 2) mean values obtained from the other sensors (any one sensor recording a value far from the other sensors is likely inaccurate, according to Sowder and Steel 2012). The mean is used for the calibration accuracy check because it is based on multiple measurements and is generally more stable than single-point measurements like the minimum and maximum. The same procedures can be used for waterproof and non-waterproof sensors, except the non-waterproof sensors should not be placed in water baths.

Table 4. Multi-point pre-deployment accuracy check

Task	Procedure
Setup	1. Connect sensor to computer. 2. Check battery health. 3. Program sensor to record at 30-minute intervals.
Test bath	4. Put sensors in an open container/s; for the water temperature sensors, fill container with enough water to fully submerge the sensors. 5. Put the container/s in a room that is at room temperature (near 20°C) for at least 4 hours (the objective is to have the temperatures to equilibrate). 6. 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 datasheet (see sample form in Appendix C). 7. Put the container with the sensors in the refrigerator (near 0°C) for at least 4 hours. 8. 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 a datasheet (Appendix C). 9. Repeat steps 5 through 8 several times to create multiple warming/cooling cycles. 10. Remove the sensors from the container/s.
Accuracy check	11. Download the data from the sensors onto a computer as soon as possible so that the sensor can be shut off to conserve battery life. 12. Calculate the overall average temperature of each individual sensor for the entire calibration period as well as the maximums and minimums of each temperature cycle. Compare the mean temperature value to the group average. For the dates and times when measurements overlapped, compare the sensor temperature values to the NIST thermometer values. Calculate the average difference between these values. It should not exceed the accuracy quoted by the manufacturer of the temperature sensor, which should be ±0.5°C or, in some cases, ±0.2°C for sensors deployed at RMN sites. Sensors that have anomalous readings should be set aside and returned to the manufacturer for replacement. 13. Record all accuracy check information on a data sheet (see sample form in Appendix C).

Whichever technique is used, differences in readings from the sensors and NIST-certified thermometers should not exceed the accuracy quoted by the manufacturer. For sensors deployed at RMN sites, that number is ±0.5°C or, in some cases, ±0.2°C. Sensors that have anomalous readings should be set aside for further testing or returned to the manufacturer for replacement. All accuracy check data should be recorded on a datasheet like the one shown in Appendix C. These records should be properly archived and stored in a place that can be easily accessed for future reference (these data will eventually be used for QA/QC procedures, as discussed in Section 2.6.1). Equipment needs for this procedure are listed in Table 5.

Table 5. Equipment needs for the pre-deployment accuracy check

Task	Supply list
Performing the calibration procedure	• Temperature sensor/s • National Institute of Standards and Technology (NIST) traceable or calibrated reference thermometer with an accuracy of ±0.2°C • Field (e.g., red liquid) thermometers (optional) • Containers to hold the sensors • Water • Refrigerator • Clock or watch
Recording measurements	• Accuracy check data sheet (Appendix C) • Computer that has the appropriate software for reading the temperature sensor

2.2.2. Sensor configuration and launch

Sensors can be programmed to start before or after the planned deployment time, or can be launched on site. Whatever the launch time, the exact time the sensor is correctly positioned should be recorded so that observations recorded before and after that time can later be removed during data processing (Section 2.6.2). Configure the sensors to record point temperature measurements in degrees Celsius at intervals of 30 minutes. If the sensor has insufficient memory capacity to record at 30-minute intervals for the deployment period, program the sensors to record point measurements every 60 or 90 minutes. Figure 6 suggests that 60-minute intervals are likely sufficient, although 30-minute intervals might more closely match other continuous data collection efforts, such as the hydrologic data being collected by the pressure transducers.

The following practices will make data processing and screening easier and more efficient:

- Set the sensors up so that they start recording on the hour (xx:00) or half hour (xx:30)
- Set the units to degrees Celsius
- Set the air and water temperature sensors up so that they record at the same time
- Consider using military time (if this is an option) to avoid potential confusion with a.m./p.m.

- Consider using local standard time (e.g., UTC-5 for sites in the Eastern Time zone) 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.

Considerations when choosing a sampling interval

Choosing a sampling interval is a balancing act. If long intervals are used, you could miss the maximum and minimum daily temperatures because they might occur only briefly within a day. Missing them would underestimate the warmest temperatures and overestimate the coldest temperatures. If too short an interval is used, too much memory could be used, requiring more site visits, data management, storage, and cleaning.

Dunham et al. (2005) compared the amount of bias in daily summary metrics that is incurred by using different recording intervals. As shown in Figure 6, until intervals longer than 2 hours are used, bias generally is not an issue. Sites with larger diel fluctuations have a greater probability of missing the true maximum than those with smaller diel fluctuations.

At RMN sites, the 30-minute interval will be reevaluated after the first or second year of data collection to determine whether a longer interval (i.e., 60 or 90 minutes) can adequately capture the thermal regimes at sites.

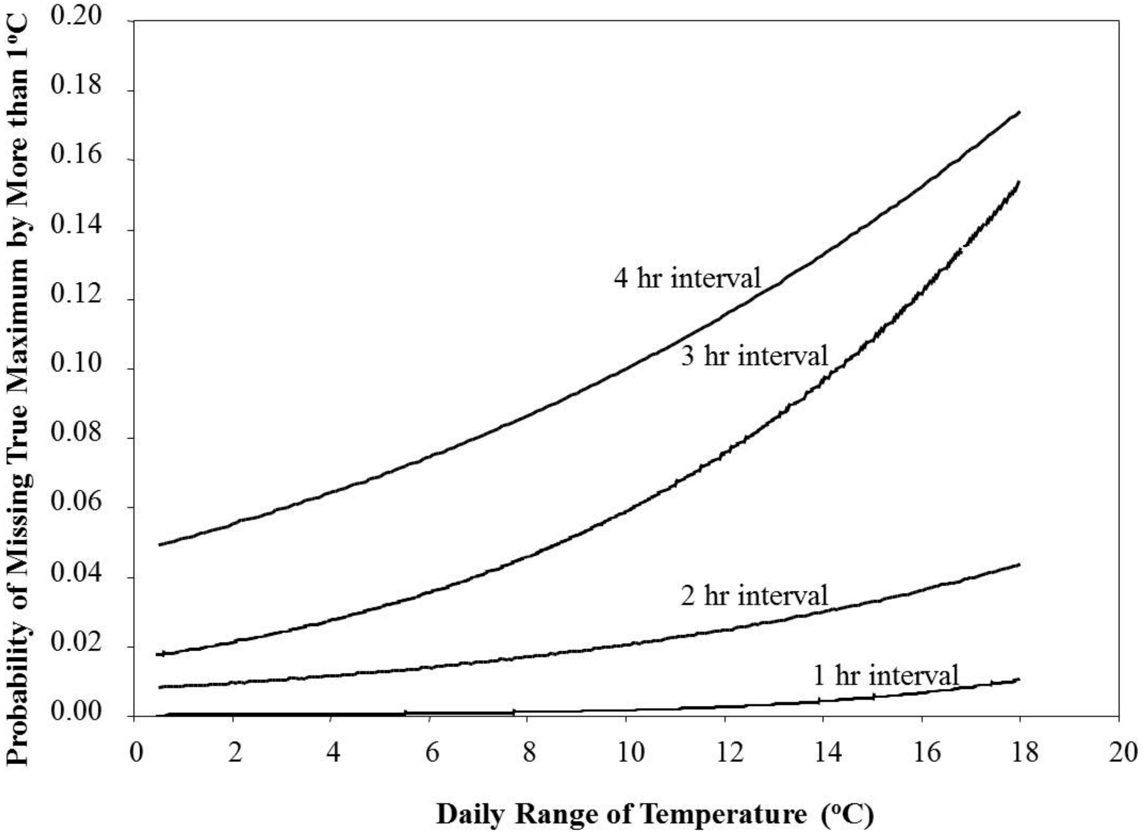


Figure 6. Probability of underestimating the maximum daily temperature at least 1°C in relation to daily range of temperature and sampling interval (Dunham et al. 2005).

Record the configuration and launch information for each sensor on a datasheet, similar to the one shown in Appendix D. Include serial number, programmed deployment time, and recording interval. If the sensor has "sensor high, low, and multiple sampling" features and "wrap-around-when-full, overwrite oldest data" functions, turn these functions off.

2.3. Deployment of Water Temperature Sensors

Deploy at least one water temperature sensor at each RMN site. Place sensors in locations that can be safely accessed and waded by crew members during different flow conditions. If possible, avoid reaches with very high gradients (>7%) because sensor retention rates are inversely related with slope (Isaak et al. 2013). Prior to installing the sensors, obtain permission from all relevant parties (e.g., property owners if site access will involve crossing private property, the local Department of Public Works if the water temperature sensor will be attached to a bridge abutment). Try to minimize site impacts.

This document describes techniques that can be used to attach sensors to natural objects in streambeds at remote sites, and also covers installations in which sensors are attached to built structures like bridges. Provided the sensor is collecting data that are representative of the characteristics of the reach from which the biological data are being collected, the sensor need not be sited in the exact location from which biota are being collected.

2.3.1. Guidelines for placement within the stream

No simple, straightforward formula for selecting a location exists because each site is different. In general, however, areas of well-mixed water moving through runs and pools are preferable over riffles. Deploy sensors in locations with as many of the following characteristics as possible, prioritized in this order:

- Representative of the characteristics of the reach from which the biological data were collected (e.g., not below additional warm or cold water sources)
- Well-mixed horizontally and vertically
- Of sufficient depth to keep the sensor submerged year round
- Stable, accessible, and easy to relocate
- Protected from physical impacts associated with high flow events (e.g., the downstream side of a large landmark rock or log)
- Low human activity to reduce vandalism and accidental snagging

How do I know if the water is well-mixed?

In general, any moving water will be well mixed. To verify this, take numerous instantaneous temperature measurements near the deployment location. If the stream can be easily waded, a simple cross-sectional temperature survey, consisting of at least 10 measurements, can be done. If crews 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 2005). If these measures exhibit a high degree of variability, consider moving to a different deployment location.

Do not select locations that:

- Are areas of high use, visibility, or fishing access
- Have heavy beaver activity
- Have backwater pools, eddies, or standing water that might stratify during low flow conditions
- Are influenced by localized warm or cool water sources, such as
    - a tributary confluence
    - an impoundment (including beaver ponds)
    - a lake outlet
    - point-source discharges
    - streamside wetland areas
    - hot springs
    - groundwater seeps

When possible, deploy sensors approximately 6 inches (<0.15 meters) above the stream bottom (per Schuett-Hames et al. 1999). In some small, shallow streams you may have no choice but to place a sensor near the stream bottom to ensure that it remains submerged during low flows. If this happens, noting this on the field form is important because: 1) the temperature readings could be influenced by groundwater and subsurface flow (Stanford and Ward 1988, Baxter and Hauer 2000, Edwards 2001); and 2) sensors on or near the streambed are more susceptible to burial by moving substrates (sensors should never be intentionally buried).

If conditions permit, install sensors on the downstream side of the structure to which the sensor is being attached (e.g., a large rock or log). Doing so will help protect the sensor from high water velocities and associated substrate movement and transport of debris that commonly damage or dislodge sensors (Dunham et al. 2005). Ideally, the structure will also hide the sensor from potential vandals.

2.3.2. Installation

If possible, install the sensor during low flow conditions to enable field personnel to check whether the water is well-mixed and of sufficient depth year round. Flow conditions can be determined by studying the hydrographs of local streams. In the next two sections, we briefly describe two installation methods: the underwater epoxy method (Isaak and Horan 2011, Isaak et al. 2013) and a method in which sensors are cabled to rebar or stable instream structures such as large rocks or boulders, woody debris, or roots (Mauger 2008, Ward 2011). Equipment needs for both techniques are listed in Appendix E. Site-specific conditions will dictate which installation technique is most appropriate. The best technique ultimately will be the one that is easiest to use and has the highest sensor retention rates over time. The pros and cons of each method are discussed in Sections 2.3.2.1 and 2.3.2.2.

2.3.2.1. Underwater epoxy

The underwater epoxy method can be used in multiple environments provided a suitable anchor point is available, such as a large rock or cement structure (e.g., bridge support). Table 6 describes the step-by-step procedure for completing underwater epoxy installations. The first step is to select an appropriate rock or cement structure. The structure must have a relatively flat downstream attachment surface and must be in water that is moving and deep enough to remain submerged for the entire year. The best structures are those that not only remain immobile during floods, but also are wide and protrude well above the low flow water surface to provide an effective shield against moving rocks and debris. (Note: do not move rocks into the channel to serve as attachment sites—if you can lift the rock, high flows will certainly dislodge it, not to mention the safety risk associated with lifting large boulders). Ideally, on the downstream side of the attachment point, pockets of relatively calm water with smaller substrate sizes will be present (if large rocks and cobbles occur on the downstream side, similarly large substrates likely will move there again during the next flood, and these could dislodge or break the sensor). Cement bridge pilings at road crossings are also good attachment points for this protocol. Photos of good attachment points are shown in Figure 7. Research has shown that heat conduction through attachment structures like these does not bias temperature measurements if installations are done in keeping with the protocols described below (Isaak and Horan 2011).

Table 6. Quick guide for doing underwater epoxy installations (Isaak et al. 2013)

Task	Procedure
Select attachment point	1. The attachment point should have the following features: • Is protruding a foot or more above the water surface at low flows (rocks of this size can be easily seen and relocated during subsequent field visits, and are large enough to prevent other rocks from sliding over them and potentially hitting the sensors during high flows) • Is wide enough to protect sensor from moving rocks/debris during floods • Has flat attachment site on downstream side and relatively deep water with flow • Has small substrate on downstream side and 8 inches of space for shuttle attachment
Installation	2. Check sensor for blinking indicator light. Record sensor serial number and metal forestry tag number on field form (Appendix D). 3. Put on gloves and use wire brush to clean surface of attachment site (approximately 6 inches above stream bed). Place a few cobbles or suitably sized rocks near the sensor site to later lean against the attached sensor. 4. Moisten gloves and scoop out small amount (about quarter-size in diameter, 1/8 in thick) of white and black epoxy from each container, and mix together for at least 1 minute. Apply epoxy to back of sensor (or PVC canister) and metal forestry tag. 5. Gently push and slightly twist sensor (or PVC solar shield holding the sensor) onto attachment site. 6. Lean a rock against the face of PVC to hold it in place while the epoxy sets and check attachment site with plastic viewing box.
Monument	7. Attach forestry tag on boulder directly above sensor (above water line). 8. Mark the site as a waypoint on GPS and record coordinates on data sheet (Appendix D). Take several photos of site, and record photo numbers on data sheet.

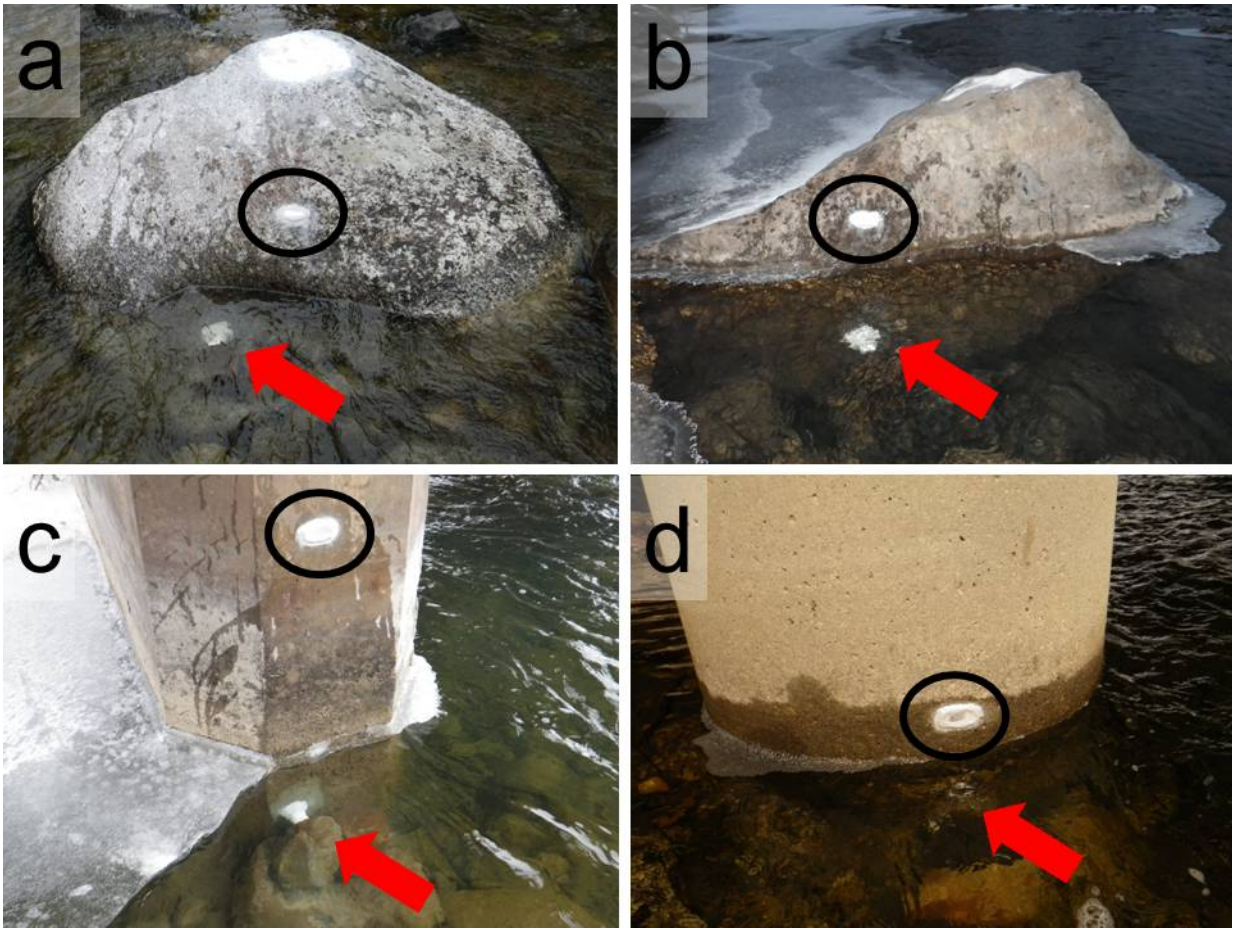


Figure 7. Examples of large rocks (a, b) and cement bridge pilings (c, d) that provide good sensor attachment sites. Each site has a flat downstream attachment surface that is shielded during floods from bedload and debris. Arrows point to the solar shield containing a sensor; circles highlight metal forestry tags epoxied above the sensor to monument the site (photos from Isaak et al. 2013).

After selecting an attachment point, use epoxy to attach the sensor to the structure, and lean a rock against the face of the PVC canister to hold it in place while the epoxy sets (Figure 8). Use of a specific underwater epoxy is critical to the success of this method. Isaak and Horan (2011) tested several types of epoxy and found that only Fox FX-764 epoxy provided durable cement-like attachments that worked well in field conditions. Installations with the Fox FX-764 epoxy work well in a wide range of temperatures (2 to 20°C), but the epoxy becomes less cohesive in water temperatures exceeding 20°C. Installations done in especially warm streams might need to be done when water temperatures are relatively cool to allow the epoxy to set (Isaak et al. 2013). Once the epoxy sets, it will hold the sensor across the full range of annual and daily water temperatures.

If you are inexperienced with this technique, complete some practice runs in the laboratory first, and then perform your first field installations at a few easily accessible locations that can be checked after a few days. If a sensor needs to be reattached to a structure that has old Fox bonding agent on it, using a different attachment point is best if possible.

Figure 8. Close-up of a PVC solar shield with a temperature sensor glued to a rock in a stream. The rocks propped against the front of the solar shield holds it in place while the epoxy sets during the first 24 hours.

Equipment needs for underwater epoxy installations are summarized in Table 7 and Figure 9. Additional details on underwater epoxy installations are available in Isaak et al. (2013) and in a YouTube training video (accessed 15 June 2013):

http://www.youtube.com/watch?v=vaYaycwfmXs&feature=youtu.be

The epoxy can also be used to attach a metal forestry tag near the sensor location. This can make the sensor easier to relocate during subsequent site visits (Figure 9). The numbers on the tags can be used as unique site identifiers. This is useful for data organization, especially if different sensors are used at a site over time (Isaak and Horan 2013).

Table 7. Equipment list for doing underwater epoxy installations (Isaak et al. 2013)

Task	Supply list
Installation	• Temperature sensor • Radiation shield (PVC canister, 1-1/2” with screw top, mid-section, base) • Underwater epoxy (FX-764 Splash Zone Epoxy) • Jars for mixing the epoxy • Underwater viewing box • Lead weights, ¼ oz • Neoprene, 3 mm • Rubber gloves • Plumber’s tape • Wire brush • Zip ties, 4” • Metal mirror
Monument[1]	• Metal forestry tags • Spray paint • GPS • Camera • Data sheet (similar to Appendix D)

[1] Monumenting is discussed in Section 2.3.3.

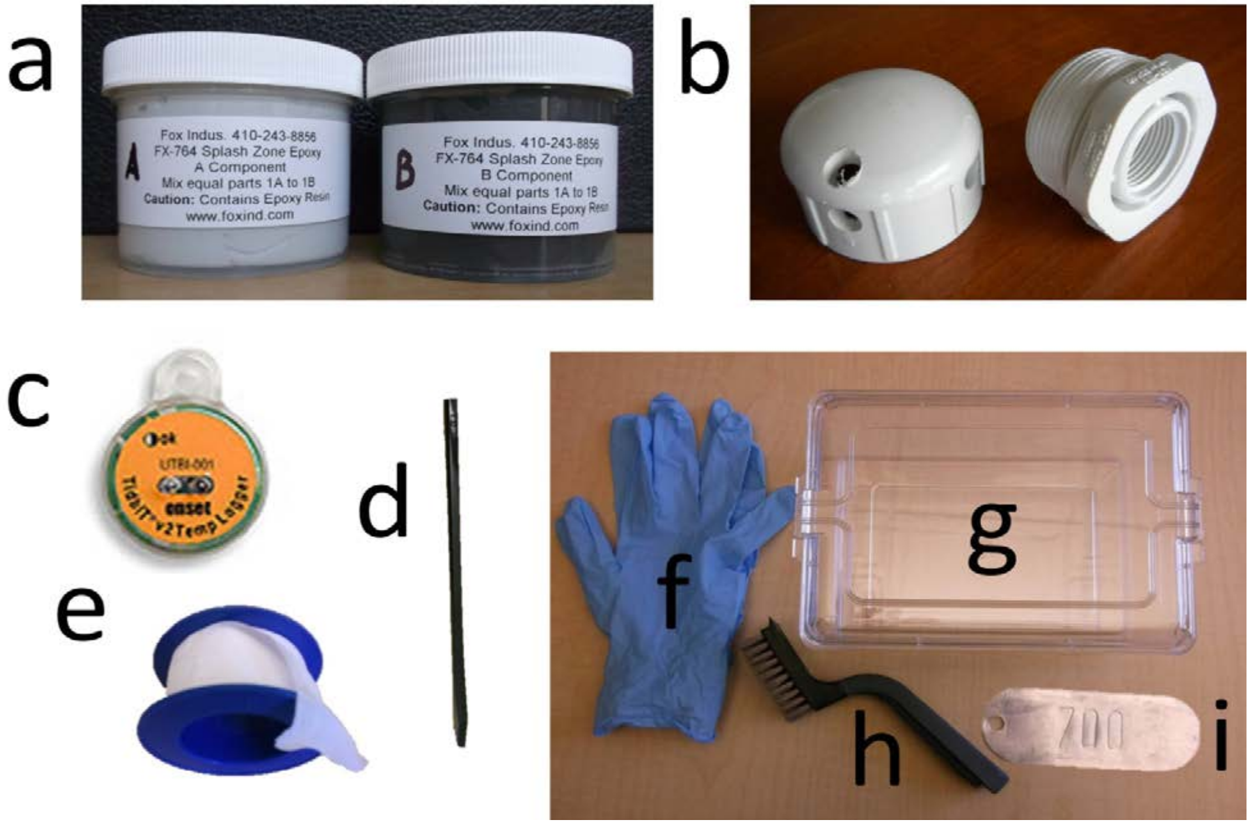


Figure 9. Equipment needed to permanently install temperature sensors in streams using underwater epoxy. The equipment includes: (a) two-part FX-764 epoxy from Fox Industries, (b) PVC solar shield, (c) temperature sensor, (d) cable ties, (e) plumber's tape, (f) rubber gloves, (g) plastic viewing box, (h) wire brush, and (i) metal forestry tree tag (Isaak and Horan 2013).

Pros and cons of the underwater epoxy method are summarized below.

Pros:

- It requires minimal effort and materials.
- It provides durable installations that have been shown to withstand floods and associated bedload movement (based on field trials, 80–90% of sensors installed correctly remained in place after 1- and 2-year intervals [Isaak et al. 2013]).
- Retention rates have been formally tested and documented in a wide variety of streams and are based on several years of field trials (Isaak et al. 2013).
- Once a sensor site is successfully established, it is easily maintained in years thereafter simply by replacing sensors in PVC housings that remain in place.

Cons

- Finding suitable attachment sites within appropriate macrohabitats (runs) might be difficult, particularly in smaller streams that lack large rocky substrates.
- The technique is used primarily with Onset Tidbit© v2 sensors. The design would have to be modified to accommodate larger sensors like the Onset Hobo© Water Temp Pro v2 sensors.
- Obtaining the epoxy might be difficult.

2.3.2.2. Cabling the sensor to rebar or stable instream structures

Sensors may be cabled to rebar or stable instream structures like large rocks or boulders, roots, or woody debris. 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. Use heavy-duty (e.g., 120-lb tensile strength) cable ties or wire to attach the sensors to the structures. If conditions permit, attach the sensor at two points, as shown in Figure 10. 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).

Figure 10. If conditions permit, attach sensors in two places, using heavy-duty (e.g., 120-lb tensile strength) cable ties. This picture was provided by MDDNR Monitoring and Non-Tidal Assessment.

If a site lacks these types of stable instream structures and the stream bottom is such that a metal stake can be driven into it (e.g., no near-surface bedrock or consolidated sediments), the rebar method can be used. An appropriately sized piece of rebar (generally 2–4 feet) is driven into the streambed, deep enough to stay in place during high stream flow events. The sensor and its protective housing are attached to the rebar via heavy-duty cable ties or wire.

If possible, use rebar that is bent as shown in Figure 11 (design provided by Christopher M. Harbourt, Principal Engineer, Waterborne Environmental, Inc. Champaign, IL. www.waterborne-env.com). If one leg of the rebar is a little longer than the other, the installations will be easier because you can start the longer leg first and then pound the rest into place. Using bent rebar has several advantages. For one, it is more secure because the metal bar is anchored in two places. A second benefit is that it poses less safety risk for people wading through the stream because no sharp points protrude upward into the water column (Personal communication, Christopher Harbourt, May 2, 2014).

Figure 11. Using bent rebar for rebar installations has several advantages. It is more secure because the metal bar is anchored in two places. It also poses less safety risk for people who are wading through the stream because no sharp points protrude upward into the water column. This design was provided by Christopher M. Harbourt, Principal Engineer, Waterborne Environmental, Inc. Champaign, IL. www.waterborne-env.com. Installations are easier if one leg is a little longer than the other because you can start the longer leg first and then pound the rest into place.

Various techniques can be used to attach the sensor and its protective housing to the rebar. Some examples are shown in Figure 12 and Figure 13. Appendix F contains detailed descriptions of two additional installation techniques. One describes the cable/rebar method that is used in Cook Inlet salmon streams in Alaska (Mauger 2008), and the second is a technique the Delaware River Basin Commission (DRBC) developed that uses a low profile concrete base.

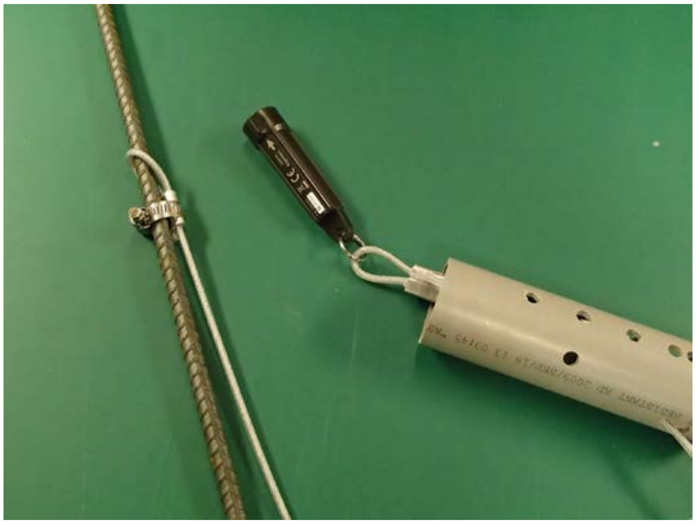


Figure 12. Example of how a cable and rebar installation is configured for large streams in Maryland. During the field installation, the cable is tightened so that the sensor sits within the PVC housing. Heavy-duty cable ties are then run through two of the side holes in the PVC housing to secure the sensor to the side of the PVC. This picture was provided by MDDNR Monitoring and Non-Tidal Assessment.

Figure 13. Example of a rebar installation in a small stream in Shenandoah National Park, VA. The sensor is located inside the PVC housing, which has several holes drilled into it to facilitate water circulation. Two additional holes are drilled into the PVC housing to serve as attachment points for the rebar. The housing slides over the rebar as shown in the picture. The housing is then secured to the rebar with a metal clamp. Hex head screws are preferred over flat heads because using a socket-end screwdriver is easier if you are working under water, especially if you are working by feel. In larger streams where flooding is more of a risk, consider using two metal clamps: one on the top and one on the bottom. That way, if the sensor becomes displaced, the housing will stay with the rebar, and an underwater metal detector can be used to help find the sensor. In larger streams, the rebar is driven deeper into the substrate than in the photo shown here. This lessens the chances of its catching on logs and other debris during high flow events and also poses less safety risk for people who are wading through the stream. This picture was provided by Craig Snyder, USGS Survey (csnyder@usgs.gov).

Pros and cons of the cabling method are summarized below.

Pros:

- Provides more flexibility in placement location than the underwater epoxy method.
- If the rebar method is used and a high flow or other event occurs that causes the sensor to become displaced, you could use a metal detector to relocate the sensor.

Cons

- For year-round deployments in streams that experience annual high flow events, sensors might be more prone to being buried or dislodged by moving substrates than sensors installed using the underwater epoxy technique.
- Retention rates are not as well documented as for the underwater epoxy method.

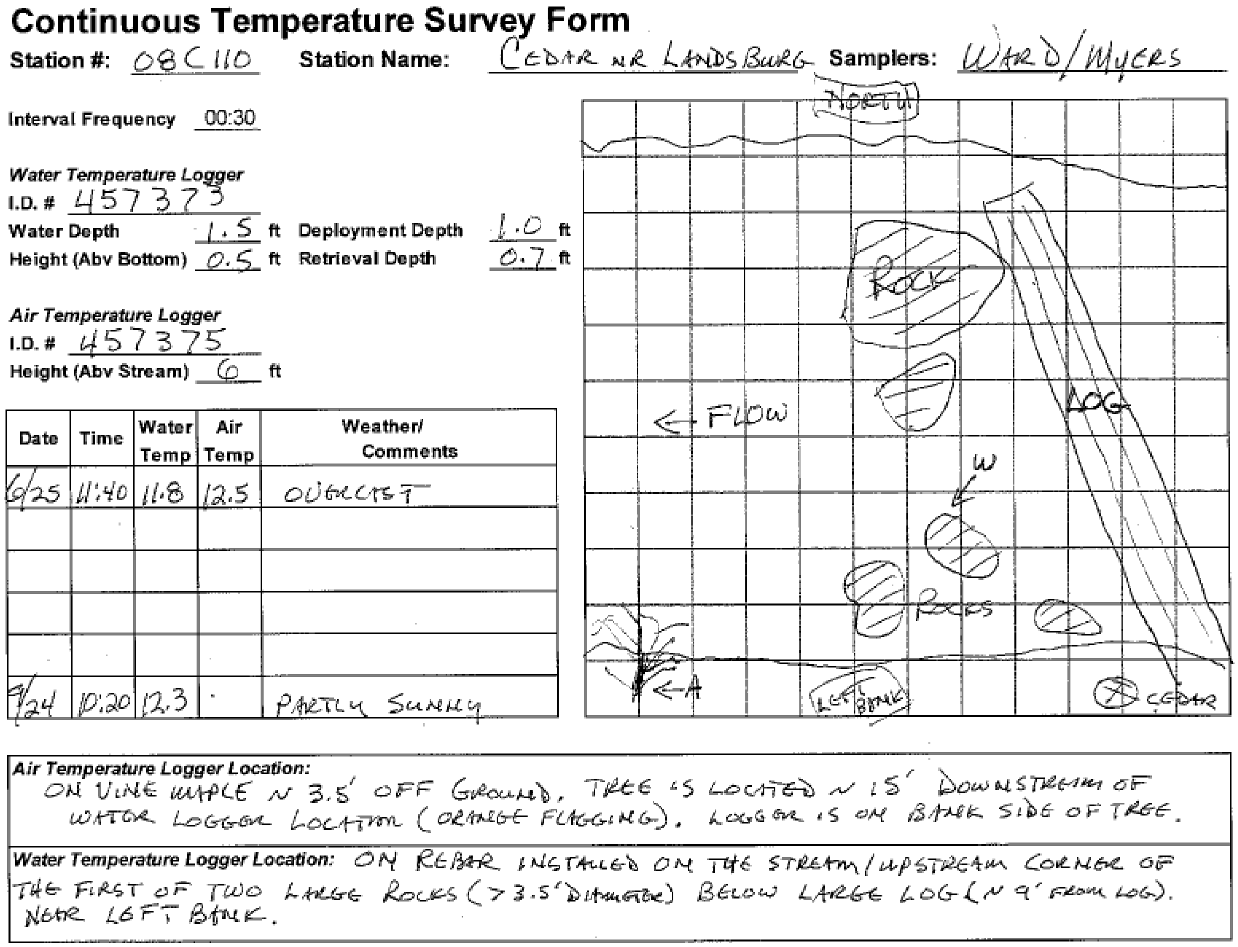
2.3.3. Documentation

One of the most common reasons for the loss of temperature sensors is failure to relocate the sensor after initial field deployment (Dunham et al. 2005). Thus, accurately georeferencing each sensor is critical as is documenting sensor placement in a way that enables field personnel to relocate the sensor during subsequent visits. Table 8 contains a list of guidelines for documenting sensor locations. First, 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. If you are unable to obtain GPS coordinates in the field, note the sensor location on an accurate map and determine the coordinates later. Although GPS coordinates are useful for getting close to the site, they are insufficient alone, so digital photos should also be taken at each site and archived in a centralized database for future use. Photographs are important for relocating the instruments, documenting any changes to the monitoring location during the course of the study, and showing the near-stream habitat of the location where the sensor is deployed.

Table 8. Guidelines for documenting the installation

Task	Procedure
Initial deployment	• Use GPS to georeference the site. • Take photographs from different perspectives; at least one photo should have a visual marker pointing to the temperature sensor. Archive photos in a central database for future use. • Make detailed hand-drawn maps with landmark references (e.g., unique rock, log, root, flagging, or tree), sensor locations, direction of stream flow, places to park, paths to the stream, and any other characteristics that might be appropriate, annotate photographs when viewing them later on a computer, or both. • Complete the field form. • Take an instantaneous stream temperature at the location of the sensor with a NIST-calibrated field thermometer. *Note: this measurement should be taken as close as possible to the time when the sensor will be recording a reading*.

Take the photos from different perspectives (e.g., upstream and downstream). Include at least one shot with a visual marker (e.g., someone pointing to the underwater location of the sensor). Later, when viewing these photos on a computer, annotate them with notes about landmark references (e.g., unique rock, log, root, flagging, tree), sensor locations, direction of stream flow, places to park, paths to the stream, and whatever else might be appropriate. Detailed hand-drawn maps like the one shown in Figure 14 (Ward 2011) are also helpful. Relocation success can also be improved by using metal forestry tags to enhance the visibility of the structures to which the sensors are attached (where suitable) (Figure 15). The use of signage at RMN sites is optional. If your agency has specific policies regarding signage, follow those protocols. Be aware, however, that using signs could increase the chance of vandalism.



Continuous Temperature Survey Form

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

Interval Frequency 00:30

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

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

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

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

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

Figure 14. Example of a hand-drawn map from a field form used by the Washington State Department of Ecology (taken from Ward 2011).

Figure 15. Metal forestry tags can be attached to the downstream side of large rocks to monument sites and air in relocation of sensors (Isaak et al. 2013).

Record all documentation information on a field form, like the sample form shown in Appendix G. Field forms should include information on station number, waterbody name, date, time, crew members, driving directions, serial number of sensor/s, time of deployment, sensor installation technique, image numbers/file names for the photographs, and detailed descriptions of sensor placement. Accurately recording the time and date of deployment is very important, as this information will be used in the error screening procedure described in Section 2.7.2.

If the stream can be easily waded, take an instantaneous stream temperature measurement with a NIST-calibrated thermometer at the location of the sensor. This measurement will be used for an accuracy check (Section 2.6.1). To minimize the chance of a faulty measurement, take the measurement as close as possible to the sensor and as close as possible to the time when the sensor is recording a measurement. Make sure sufficient time has passed to allow the NIST-calibrated field thermometer to stabilize before recording the measurement and note whether the time is standard or daylight savings time. Equipment needs for taking these measurements and for documenting sensors are summarized in Table 9.

Table 9. Equipment list for documenting sites

Task	Supply list
Georeferencing and monumenting	• GPS • Camera • Map or gazetteer, or both • Metal forestry tags • Field form (similar to Appendix D, Figure 3.3-4)
Measuring temperature	• NIST-calibrated field thermometer or multi-probe meter, or both

2.3.4. Common problems

As summarized in Dunham et al. (2005), the three most common problems that cause sensors to be damaged or lost are:

- failure to relocate the temperature sensor after initial field deployment
- human tampering or vandalism; and
- natural disturbances, such as flooding, substrate movement, and animal influences (e.g., trampling by livestock or wildlife, beaver pond construction)

Tips for minimizing the chances of losing sensors are summarized in Table 10. If there are sites where problems such as vandalism are expected to occur, consider deploying more than one sensor so that one can serve as a back-up. If you are using metal cables, clamps or rebar for installations and the sensor becomes displaced, consider using an underwater metal detector to help relocate the sensor.

Does ice affect the sensors?

Not if the sensors are properly installed and remain submerged during winter. Ice in a stream is 0°C, so it will not bias winter water temperature readings, which are also near 0°C when ice is present. If the sensor is securely attached to the downstream side of a large boulder or other protective structure, chunks of ice moving downstream will not affect it.

Table 10. Tips for minimizing the chance of sensors being lost or damaged

Problem	Tips for minimizing chance of damage or loss
Failure to relocate sensor after initial deployment	Follow the documentation steps described in Section 2.3.3, which include: • Georeferencing all sensors • Monumenting sites with metal forestry tags • Taking photographs • Creating detailed maps and notes
Disruption or vandalism from humans or livestock	• Do not put sensors in areas of high use, visibility, or fishing access • Camouflage the sensors (this is generally the least expensive option, but could also make the data sensor more difficult to relocate) • Secure the sensor in locked and signed housing that is relatively impervious to physical vandalism or disruption • Actively coordinate with ongoing research, monitoring, or management efforts in the study area, not only to minimize duplication of temperature sampling efforts, but also to minimize problems with unintentional interference
Natural disturbances	• Where possible, install sensors on the downstream side of a large landmark rock or log, as this will protect the sensor from moving rocks or debris during floods • Do not site sensors in areas with known beaver activity • House the sensor in a protective case

2.4. Deployment of Air Temperature Sensors

Air temperature plays an important role in controlling stream temperature (Hill et al. 2013). As discussed in Section 2.1.4, unbiased air temperature measurements can be difficult to obtain. If the sensor is located in an open area with full sun, unless a mechanically aspirated radiation shield is used (which requires power to run a small fan), bias will be associated with the radiation shield. If the sensor is located in a shady area near a stream, air temperature will be affected by the distance from the water (the closer the sensor is to the stream, the more the water buffers the air temperature because energy goes into evaporating stream water rather than warming the ground and air).

The objective at RMN sites is to measure streamside temperature. The streamside air temperature data will be used to gain a better understanding of the relationship between air and water temperature at each RMN site. These data will provide important insights about the responsiveness of stream temperatures to air temperatures and the differing vulnerabilities of streams to thermal change. To capture this relationship effectively, the location of the air temperature sensor in relation to the water temperature sensor must remain constant throughout the period of data collection. Although air temperature has a strong effect on stream temperature, many other controls, such as groundwater discharge, affect stream temperature. Although these other controlling factors are of interest, due to resource limitations, only air temperature can be consistently collected at RMN sites at this time.

At least one air temperature sensor should be deployed at each RMN site. If the riparian zone is forested (which is likely—most of the RMN sites are located in forested watersheds), mount the air temperature sensor to the tree that is: 1) nearest the water temperature sensor, and 2) large enough to support the radiation shield and sensor (ideally >12 inches (0.305 meters) in diameter). Trees generally make the best attachment points because they provide stability, some degree of shade, and can help hide the sensor from potential vandals. If a suitable tree is present, attach the radiation shield and sensor to its north side, out of direct sunlight, using the simple four-step process described in Appendix B. Outfitting the temperature sensors with radiation shields is critical so that sunlight does not strike the sensor and bias the temperature readings (Dunham et al. 2005, Isaak and Horan 2011) (Section 2.1.4). Do not rely on vegetation alone as the primary radiation shield.

To be consistent with typical meteorological observations, air sensors should be placed at a height of 2 meters, or approximately 6 feet, off the ground. Because trees, vegetation, and the ground create radiation microenvironments, try to minimize the amount of other vegetation near the sensor. If the air temperature sensor is not waterproof, ensure that the radiation shield provides sufficient protection from the elements.

If trees or other suitable, stable existing structures (e.g., fence posts) are absent, mount the radiation shield and air temperature sensor to a 10-foot piece of 1/2-inch diameter PVC pipe, which can be purchased at a local building supply store. Using a drill, create a 1/8-inch hole in the PVC pipe at a height of 2 meters above the ground. Next, insert a 12-inch piece of heavy-gauge steel wire (a metal coat hanger works well) through the hole. This metal wire can be inserted through one of the small corrugated tubes at the top of the solar radiation shield. Plastic zip ties can then be used to stabilize and secure the solar radiation shield to the PVC pipe. Then, pound a 3- to 4-foot piece of metal rebar into the ground to a depth of approximately 1-foot, and slide the PVC pipe onto the rebar. This method has limitations. For one, it has only been used experimentally and has not been extensively tested. Another is that sensors installed in the open are more likely to be vandalized, and may also be more prone to destruction by animals.

Installations should be documented per the procedures outlined in Section 2.3.3. After installation and during subsequent site visits, instantaneous air temperature measurements should be taken with a NIST-calibrated thermometer at the location of the sensor, as close as possible to the time of the expected sensor recording. These data will later be used to check the accuracy of the sensor (Section 2.6.1).

If an air temperature sensor cannot be installed at a site, compile daily air temperature observations from the nearest active weather station. Online resources like Utah State University's Climate Database Server (http://climate.usurf.usu.edu/mapGUI/mapGUI.php) can be used to locate the nearest weather station and to obtain data. How well the weather station data approximate on-site conditions depends on factors such as distance between the site and weather station and differences in topography and weather patterns. Local surface air temperatures can vary substantially (5–10°C) from nearby weather stations in mountainous terrain. This is particularly true in valleys, where temperature can become decoupled from the free atmosphere as a result of cold air drainage and pooling (Holden et al. 2011).

Obtaining data from the nearest weather station is of value even if an air temperature sensor is installed at a site. The data could be used for QA/QC purposes (e.g., a comparison of the two datasets that reveals differences in patterns could indicate that the on-site sensor is malfunctioning). Or, if the comparison shows little difference between data sets, the weather station data could be used in place of the data from the on-site sensor. This would free up a temperature sensor for use elsewhere, which could be important if resources are limited.

2.5. Maintenance/Mid-Deployment Checks and Data Offload

After equipment is installed at a RMN site, try to revisit the site within the first month to confirm that the installation is holding properly and that the sensor remains fully submerged in flowing water. After these initial deployment checks, visit the sites as frequently as your schedule permits to check the condition of the sensors, gather data for mid-deployment accuracy checks and offload data. More frequent site visits will help ensure the longevity of the sensors as well as data quality. At a minimum, try to visit the RMN sites annually, ideally during low flow conditions.

To gather data for the mid-deployment accuracy checks, collect instantaneous stream temperature measurements near the sensor with a NIST-calibrated field thermometer. To minimize the chance of a faulty measurement, take the measurement as close as possible to the sensor and as close as possible to the time when the sensor is recording a measurement, make sure sufficient time has passed to allow the NIST-calibrated field thermometer to stabilize before recording the measurement and note on your field form whether the time is standard or daylight savings time.

A biofouling check can also be performed but is optional at RMN sites. To perform this check, remove the sensor and gently clean it (per manufacturer's instructions) to remove any biofilm or sediment, then return the cleaned sensor to the stream. Note on your field form the time at which the "pre-cleaning" measurement was made and the time of the first "post cleaning" measurement. Compare the readings.

If possible, bring a laptop (with the appropriate software) and base station or waterproof shuttle into the field so that the data can be offloaded onto the computer on-site. This allows field personnel to:

- quickly screen the data for atypical results (if any readings are unusual, consider replacing the sensor or moving it to a different location, e.g., perhaps the sensor is coming out of the water during baseflow conditions)
- check the battery life on certain types of sensors (batteries in some sensors should be replaced each year, while others, like the Onset TidbiT v2, last five years or longer under normal use)
- back up the data (e.g., onto a flash drive) before clearing the sensor memory

Table 11 and Appendix G contain checklists for performing these maintenance/mid-deployment checks and data downloads. Note things that could affect the quality of your data, such as signs of physical damage, vandalism, or disturbance. Also ensure that the sensor is not buried by sediment and remove anything that could foul the sensor and bias the temperature readings (e.g., debris, aquatic vegetation, algae). Take photographs to document any changes to the monitoring location during the course of the study.

Table 11. Checklists for performing maintenance/mid-deployment checks and data downloads

Task	**Procedure**
Maintenance/ mid-deployment checks	• Check the security of the housing and deployment equipment and adjust if necessary. • Look for signs of physical damage, vandalism, or disturbance. • Ensure that the sensor is submerged. If it is not, move it to a location where it is covered by water and will remain so during periods of base-flow. • Ensure the sensor is not buried in sediment. If it is, remove the sediment and reinstall the sensor where it will not be buried during future high flow events. Note on the datasheet that the sensor was buried because temperature recordings are likely to be significantly biased toward cooler temperatures by hyporheic flows. In many cases, temperature recordings from buried sensors should be discarded because of high bias and because accurate adjustments are difficult to apply. • Remove anything that could bias the temperature readings (e.g., debris, aquatic vegetation, algae). Note: if sensors have protective housings with fine screens or small flow-through holes, they can be easily fouled in eutrophic systems with abundant periphyton or algal growth. • Take photos to document any changes to the monitoring location (particularly those that could influence readings). • Take instantaneous stream temperature measurements at the location of the sensor with a NIST-calibrated field thermometer. *Note: this measurement should be taken as close as possible to the time when the sensor will be recording a reading.* • Record observations on the field form (like the one shown in Appendix G). • OPTIONAL: Biofouling check. Remove the sensor and gently clean it (per manufacturer's instructions) to remove any biofilm or sediment, then return the cleaned sensor to the stream. Note on your field form the time the 'pre-cleaning' measurement was made and the time of the first 'post cleaning' measurement. Compare the readings.
Data offload	• Before connecting the sensor to the data offload device, gently 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. • Attach the sensor to a base station or shuttle and then connect the data offload device to a computer with the appropriate software. • Once the connection is established, follow manufacturer's downloading procedures. • Clear the sensor memory as necessary to ensure sufficient capacity for continued deployment.
Sensor retrieval	• If a sensor is removed from a site, before leaving the site, mark it with a temporary tag identifying the site, date, and time of retrieval. • Be sure to record the exact times of deployment (in proper position) and recovery. This information is needed for trimming data after retrieval.

Table 11. **Checklists for performing maintenance/mid-deployment checks and data downloads (continued)**

Task	Procedure
Data offload	• Before connecting the sensor to the data offload device, gently 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. • Attach the sensor to a base station or shuttle and then connect the data offload device to a computer with the appropriate software. • Once the connection is established, follow manufacturer's downloading procedures. • Clear the sensor memory as necessary to ensure sufficient capacity for continued deployment.
Sensor retrieval	• If a sensor is removed from a site, before leaving the site, mark it with a temporary tag identifying the site, date, and time of retrieval. • Be sure to record the exact times of deployment (in proper position) and recovery. This information is needed for trimming data after retrieval.

To gather data for the mid-deployment accuracy checks, collect instantaneous stream temperature measurements near the sensor with a NIST-calibrated field thermometer. To minimize the chance of a faulty measurement, take the measurement as close as possible to the sensor and as close as possible to the time when the sensor is recording a measurement, make sure sufficient time has passed to allow the NIST-calibrated field thermometer to stabilize before recording the measurement and note on your field form whether the time is standard or daylight savings time.

A biofouling check can also be performed but is optional at RMN sites. To perform this check, remove the sensor and gently clean it (per manufacturer's instructions) to remove any biofilm or sediment, then return the cleaned sensor to the stream. Note on your field form the time at which the "pre-cleaning" measurement was made and the time of the first "post cleaning" measurement. Compare the readings.

If possible, bring a laptop (with the appropriate software) and base station or waterproof shuttle into the field so that the data can be offloaded onto the computer on-site. This allows field personnel to:

- quickly screen the data for atypical results (if any readings are unusual, consider replacing the sensor or moving it to a different location, e.g., perhaps the sensor is coming out of the water during baseflow conditions)
- check the battery life on certain types of sensors (batteries in some sensors should be replaced each year, while others, like the Onset TidbiT v2, last five years or longer under normal use)
- back up the data (e.g., onto a flash drive) before clearing the sensor memory

If bringing a laptop into the field is impractical, offload the data onto a portable data storage device (like the Onset waterproof shuttle) and view it later when you have access to a computer. Data should be transferred from the data offload device to a computer as soon as possible.

If the sensor is functioning properly and has sufficient battery life, it can be redeployed at the site. If the sensor is removed from the site, before leaving the site, mark the sensor with a temporary tag identifying the site, date, and time of retrieval, and replace it with another sensor that has passed a pre-deployment accuracy check (Section 2.2.1). Accurately recording the time and date of retrieval is critical, as this information will be used in the error screening described in Section 2.7.2. When you replace a sensor, if the original one was not permanently attached to a structure, put the sensor as close as possible to the original location to minimize potential sources of variability in the long-term record. That comprehensive field notes be taken during every site visit is essential. Sample field forms can be found in Appendix G. Equipment needs for maintenance, mid-deployment checks, and data downloads are summarized in Table 12.

2.6. Quality Assurance and Control

Perform QA/QC procedures after data are offloaded to verify the quality of the data and to check for potential errors. Document these procedures (e.g., on a form like the one shown in Appendix H). Any forms and other documentation should be organized, easily accessible, and archived in a way that allows for safe, long-term storage. The series of data cleaning steps described in Section 2.6.2 can improve data quality, reduce the time and effort of data processing, and increase collaboration and comparability across projects, streams, and regions (Sowder and Steele 2012).

Table 12. Equipment list for conducting maintenance/mid-deployment checks and data downloads

Task	Supply list
Relocating sensor	• GPS • Map, gazetteer, or both • Annotated photos or hand-drawn map with landmark references (see Section 2.3.3)
Documenting on-site conditions	• Camera • Field form (similar to Appendix E)
Data offloads	• Base station or portable shuttle • Laptop (if practical) and data back-up device (e.g., flash drive)
Measuring temperature	• NIST-calibrated field thermometer, multi-probe meter, or both
Back-up equipment (in case a sensor needs to be replaced)	• Calibrated replacement sensors and other necessary deployment equipment

2.6.1. Mid- and post-deployment accuracy checks

After sensor data are downloaded, 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 with an appropriate data qualifier, and review the field notes to look for comments about situations that could cause the NIST-calibrated field thermometer measurement to be faulty (e.g., perhaps the crew could not take the measurement in close proximity to the temperature sensor due to high flow conditions, or used daylight savings time instead of standard time when recording the time of the measurement). If no issues with the NIST-calibrated field thermometer measurement are documented, consider replacing the sensor. After the sensors are retrieved and brought back to the office or laboratory, conduct a post-deployment accuracy check on each sensor, using one of the pre-deployment accuracy check procedures described in Section 2.2.1.

2.6.2. Error screening

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

- they could become dewatered during low flow conditions
- high flow events could bury them in sediment
- high flow events could move them
- they could become fouled from debris, aquatic vegetation, or algae
- humans could cause interference

Therefore, a standard set of procedures should be performed to ensure the quality of the data and make necessary corrections. A series of error screening checks based on guidance from Dunham et al. (2005) and Sowder and Steel (2012) is described in Table 13, and Appendix H contains a data screening checklist. The first step involves removing observations recorded before and after the sensor is correctly positioned. 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 dewatered or buried in the sand) and flag those data accordingly.

Next, plot all temperature measurements versus date/time and visually check the data. Look for missing data and abnormalities, Consider plotting air and stream temperature on the same graph, as well as stream temperature and stage (depth) data (if available). Specific errors to watch for include missing data; a close correspondence between water and air temperature (this indicates that the stream sensor might have been out of the water); and diel fluxes with flat tops (this indicates that the sensor might have been buried in sediment). In addition, consider performing the following optional checks: graphically compare data across sites; graphically compare data across years (dramatically different data from one year indicates possible errors); graphically compare with data from the nearest active weather station (if appropriate). If discrepancies occur, use the plots to specify the time and duration of errors in the raw data files.

Table 13. Error screening procedure (Dunham et al. 2005, Sowder and Steel 2012, Personal communication, Michael Kashiwagi (MDDNR), April 17, 2014, Personal communication, Dustin Shull (PADEP), February 2, 2014)

Task	Procedure
Remove pre- and post-deployment observations	• Use field notes indicating the exact times of deployment and recovery to remove observations recorded before and after the sensor is correctly positioned in the stream channel.
Visual checks	• Plot individual data points versus date/time to look for missing data and abnormalities • 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 • Optional: Graphically compare data across sites • Optional: Graphically compare data across years; when data from one year are dramatically different, data errors might be present • Optional: Graphically compare with stage data (if available)
Automated checks	• Calculate upper and lower 5th percentiles of the data • Flag data points for potential errors if they: o Exceed a thermal maximum of 25°C* o Exceed a thermal minimum of −1°C* o Exceed a daily change of 10°C* o Exceed the upper 5th percentile of the overall distribution o Fall below the lower 5th percentile of the overall distribution *These values should be adjusted to thermal limits appropriate for each location.

Additional checks are described in Table 13 and Appendix H. These include flagging data points for potential errors if they fall outside expected thermal limits (e.g., if water temperature measurements exceed a thermal maximum of 25°C or a daily change of 10°C). Thresholds should be adjusted to thermal limits that are appropriate for each site.

Various software applications can be used to help with the error screening checks, data management, and calculation of various summary statistics. The software purchased with the temperature sensors is likely to have some applications like this. Other options include free applications that can be downloaded from the U.S. Forest Service, Rocky Mountain Research Station stream temperature website (2014) (http://www.fs.fed.us/rm/boise/AWAE/projects/stream_temperature.shtml), which include a SAS temperature data processing macro and the Thermo Stat 3 software package (Jones and Schmidt 2012). The Washington State Department of Ecology also has developed the Freshwater Monitoring Unit (FMU) Access® Data Logger Database, available upon request (Ward 2011).

Errors should be addressed on a case-by-case basis. In general, three possible actions can be taken: 1) leave data as is; 2) apply correction factor; or 3) remove data. If you are inexperienced at addressing errors with continuous temperature data, consider seeking guidance from someone with more experience and consult references like Wagner et al. (2006). Table 14 provides a general summary of different types of problems that can occur (e.g., missing data, failed accuracy check) and recommended actions for addressing them.

Table 14. General summary of different types of problems that can occur with continuous temperature data and recommended actions for addressing them

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	General rules: • 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.

Corrections should not be made unless the cause(s) of error(s) can be validated or explained in the field notes or by comparison with information from nearby stations. Accurate field notes and accuracy check logs are essential in the data correction process. Any discrepancies should be documented in your data file and any actions you take should also be carefully documented.

2.6.3. Record keeping

Even if the set of standardized procedures described in Section 2.6.2 is followed, the data cleaning process is inherently subjective, so both the original and the cleaned data files should be maintained and archived. Large amounts of stream temperature data will accumulate quickly so a central database should be developed and maintained from the initial stages of monitoring. Any changes you make to the data should be carefully documented, and all forms should be organized, easily accessible, and archived in a way that allows for safe, long-term storage.

3. HYDROLOGY

The protocols in this section describe how to install and maintain pressure transducers and staff gages to measure continuous stage (depth). If additional measurements are taken, stage data can be converted to discharge (flow). Section 3.8 contains a brief description of how to collect the discharge measurements that are used to develop stage-discharge curves. Protocols and methods discussed in the following sections are based on those used by Massachusetts Division of Ecological Restorations River Instream Flow Stewards Program (RIFLS) (Chase 2005, Division of Ecological Restoration 2010), the USGS (Rantz et al. 1982), and the Washington Department of Ecology (Shedd 2011, Shedd and Springer 2012).

3.1. Equipment

This section describes equipment used to collect stream stage data, using a combination of sensors for making continuous measurements and graduated staff gages for making discrete field measurements. Many different types of sensors can provide continuous monitoring and logging of stream stage. In this document, we focus on pressure transducers because most entities will be using these at RMN sites.

3.1.1. Basic components

Two basic components are required to measure stream stage over time:

- A submersible pressure transducer, which provides continuous monitoring and logging of water level (Section 3.1.4)
- A staff gage, which is a graduated measuring instrument from which stage can be visually read (Section 3.1.3)

Pressure transducers record absolute pressure (air pressure + water pressure), from which air pressure must be subtracted to yield water pressure. Software programs can then be used to convert water pressure to water level using the density of water. Because atmospheric pressure changes with weather and altitude, compensating for barometric variations is necessary; failure to account for these variations could result in errors of 0.6 m (2 ft) or more.

Adjustments can be made in two ways: 1) if the transducer is vented, it has a vented cable that references and automatically corrects for atmospheric pressure; or 2) if the transducer is non-vented, barometric pressure readings must be obtained from a separate device that is located nearby on land, and after both sets of data are downloaded, software is used to correct the water level data for the barometric variations. Vented and non-vented transducers are discussed in more detail in Section 3.1.2.

To access the data, a data offload device is required. This device can be a cable supplied with the transducer that connects directly from the data logger to a computer or a data shuttle that is purchased separately. The data shuttle used for the Onset temperature sensors (shown in Section 2.1.3 and Figure 2) can also be used with Onset pressure transducers by attaching a different coupler. Additional software, specific to the pressure transducer, is necessary to view the data.

Additional equipment needed for installation can be found in Section 3.3 and Appendix I.

3.1.2. Considerations when choosing pressure transducers

Pressure transducers are of two main types:

- **Vented pressure transducers**, which collect and automatically correct data for barometric pressure. These typically have transducers that are connected via vented cables to data loggers that are installed on land.
  - Pros:

    The transducer does not need to be removed from the stream to download data (data are downloaded directly from the on-land logger). Data downloads are quick and convenient. You do not risk accidentally putting the transducer back at a different elevation, which would necessitate the collection of new correction data.

    - Data are automatically corrected for barometric pressure, allowing for an immediate comparison of transducer data to gage data. This facilitates immediate detection and troubleshooting of any data quality issues in the field.
  - Cons:
    - Maintenance of the vented cable can include changing desiccant and ensuring the cable is not damaged (e.g., ensuring animals did not chew cable). Extra precautions must be taken to ensure ice does not crimp vented cable in streams with ice cover.
    - Cable lengths are fixed, meaning that cables might not be long enough to allow the logger to be placed in a convenient location or might be so long that long loops must be stored in unwieldy coils.
    - The transducer can be subject to higher rates of vandalism compared to non-vented transducers due to visibility of the on-land data sensor and cable.

- **Non-vented pressure transducers**, which do not automatically correct data for barometric pressure. This type of transducer typically has an internal data logger.
  - Pros:
    - Data loggers are internal and the transducer can be easier to hide in the stream than a vented transducer.
    - There is no vented cable to maintain. These transducers might be easier to use in streams with extended ice cover due to the lack of cable.
  - Cons:
    - A second, identical pressure transducer must be installed on land to collect barometric pressure for the correction.
    - Data must be corrected for barometric pressure post-download using the manufacturer-provided software. Data cannot be viewed in real time and unless data correction is done in the field, stage data cannot be viewed immediately.
    - Data loggers are typically located inside the transducer and therefore must be removed from the stream to download data. If the transducer is not returned to the same location and elevation, new correction data will need to be collected.

Transducers at RMN sites should meet the following specifications:

- **Accuracy of ≤ 0.015 ft**. Accuracy is a function of the operational range of the pressure transducer. As the range increases, the accuracy decreases. Manufacturers specify a full-scale accuracy for a given transducer; multiply this by the expected range of depths to be experienced by the transducer to assess whether the equipment will provide an appropriate level of accuracy. For example, a transducer with a full scale accuracy of ±0.1% should not be used over a range of depths greater than 15 feet.
- **Range to encompass the maximum expected range of stream stages for that location**. A site visit prior to purchasing the transducer will help determine the expected range of flows. Because accuracy decreases as range increases, choose the smallest possible range. A depth range of less than 15 feet should be suitable at most RMN sites.

If I am using a non-vented transducer, is it ok to use barometric pressure data from the nearest active weather station instead of deploying an on-land transducer?

Barometric pressure can vary over very small distances due to factors such as elevation and topography, so this should be evaluated on a site-by-site basis. The best way to evaluate how well the weather station data approximate on-site conditions is by collecting on-land transducer data for a year and comparing those data to the weather station data. If the two datasets are closely matched, the on-land transducer could be removed from the site. Additional considerations should be taken into account as well (e.g., Is the weather station expected to remain in operation during the period of deployment? What quality assurance and control measures are performed on the weather station data? At what rate are data collected, and do they need to be matched or interpolated to match with the in-stream transducer data?). Whichever data source is used, it is critical that the barometric pressure readings accurately represent on-site conditions because failure to account for pressure variations will result in erroneous water level measurements.

- **Sufficient cable length to meet installation requirements** (vented transducers only). Some transducers come with a standard 25-foot cable while others must be specified. A site visit prior to purchase will determine the length needed. If a site visit is not possible, a 50-foot cable is typically sufficient (see Section 3.3.2.2).

Examples and pictures, respectively, of some commercially available pressure transducers are found in Table 15 (on the next page) and Figure 16. Research your options carefully, and be sure to account for the fact that non-vented transducers might require purchasing a second transducer to measure barometric pressure on land. Also consider battery type (replaceable vs. non-replaceable) and memory capacity.

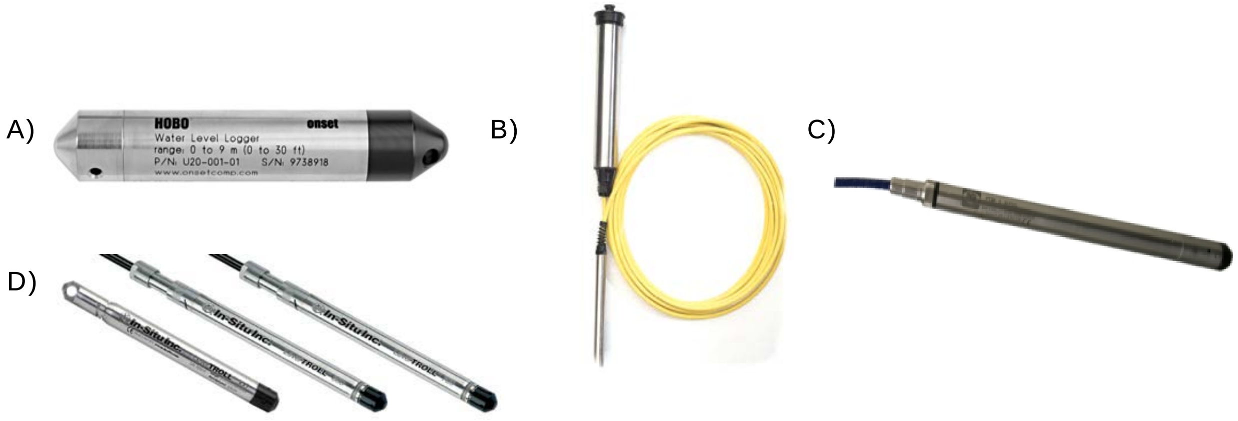


Figure 16. Numerous pressure transducers are commercially available. Some examples include: A) Onset Hobo© Water Level Data Logger; B) Global Waters Water level logger (WL16); C) INW Submersible Pressure & Temperature Smart Sensor (PT2X); and D) In-Situ Level TROLL.

3.1.3. Staff gage

Staff gages allow for instantaneous readings in the field, verification of transducer readings, and correction of transducer drift. In addition, if securely installed, the staff gage can potentially provide an attachment point for the transducer. Gages at RMN sites should be USGS style (Type A) and marked every 0.02 feet (Figure 17).

Table 15. Examples of commercially available pressure transducers

Manufacturer and sensor model	Type[1]	Ranges available (ft) that meet accuracy standards[2]	Accuracy[3]	Battery life (typical use) and replaceability	Logger memory	Approx. price[4] ($)	Website
Onset Hobo© Water Level Data Logger (U20)	Non-vented	0–13, 0–30	±0.05% Full Scale (typical); ±0.1% Full scale (maximum)	5 years with 1 minute or greater logging interval; factory replaceable	Approx. 21,700 records[5] (64K bytes)	$495 (instream) + $495 (on land)	www.onsetcomp.com
Global Waters Water Level Logger (WL16)	Vented	0–3, 0–15	±0.1% Full Scale at constant temperature, ±0.2% over 35°F to 70°F	Up to 1 year (depending on recording intervals); user replaceable (9V DC batteries)	Approx. 81,759 records	$989 (with 25 ft of cable)	www.globalw.com
INW Submersible Pressure & Temp. Smart Sensor with Datalogging (PT2X)	Vented or Non-Vented	Vented: 0–2.3, 0–5.8, and 0–12 Non-vented: 0–12	±0.05% Full Scale (typical), ±0.1% Full scale (maximum)	18 months at 15-minute interval; user replaceable (AA batteries)	Available in 130,000-, 260,000-, and 520,000-record versions	$1,095 (plus $2.35/ft cable)	http://inwusa.com
In-Situ Level TROLL 500 & 700	Vented	0–11.5	±0.05% Full Scale (at 15° C), ±0.1% Full Scale (maximum)	10 years or 2 million readings	130,000 records (2.0 MB)	$1,170 (plus cable if needed)	www.in-situ.com

[1] Transducers can be either vented or non-vented (see Section 3.1.2 for more information). Non-vented transducers require an additional transducer to collect barometric pressure data. Some manufacturers sell both vented and non-vented versions of the same transducers.

[2] Only ranges that meet accuracy standards are included in this table. Smaller depth ranges have higher accuracy.

[3] Accuracy will vary based on selected depth range of transducer. Accuracy is calculated as a percentage of the “full scale” (depth range) of the transducer. Small depth ranges will have the highest accuracy.

[4] As of January 2013 and subject to change; reduced prices might be available for bulk orders.

[5] Readings can be taken at 15-minute intervals for approximately 112 days before the memory capacity is reached.

3.1.4. Protective housing

Instream pressure transducers at RMN sites should be encased in housings to protect them from currents, debris, ice, and other stressors. Inexpensive housings can be constructed from 1.25-in or 1.5-in diameter Schedule 40 (or stronger) PVC pipe. Multiple 1/2-inch or larger holes should be drilled into the PVC to allow water to fluctuate at the same rate as in the stream (Figure 18). Factory-slotted PVC pipe with 0.010 slots, which is widely available for use in monitoring wells and piezometers, would also work well because it allows the free exchange of water while also keeping out fine sediments, debris, and biota. Some transducers, like the one shown in Figure 19, come in protective metal cases and do not need to be encased in an additional housing. In streams that are subject to extended ice cover, the entire length of the transducer and the vented cable can be encased to prevent potential damage. If vandalism is a concern, the housings can be painted black or camouflage to make them less visible.

Figure 17. Example of a USGS style staff gage (Type A) marked in 0.02-foot increments.

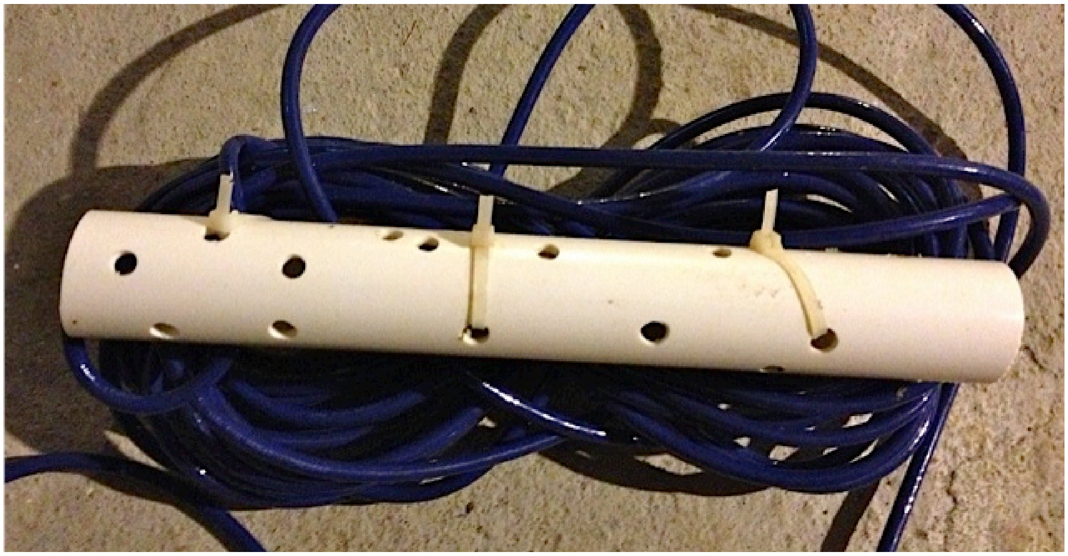


Figure 18. Example of a protective housing made of PVC pipe. This one is for a vented pressure transducer, which is secured inside the pipe with zip ties.

3.2. Pre-Deployment

Prior to deploying the pressure transducer, check the transducer to ensure the batteries will last until the next field visit. If the sensor has previously been deployed, gently clean it (see transducer manual for cleaning methods) prior to redeployment.

3.2.1. Accuracy Check

Most transducers will be factory calibrated prior to being shipped. The accuracy of the transducers should be checked over time by comparing transducer data to staff gage data or by measuring the depth of water over the transducer with a stadia rod or other measuring device. Data should be compared over a variety of water depths to ensure the transducer is accurate over the full range of depths. Most entities lack access to the type of facility that is needed to calibrate the transducers, so post-deployment field checks are typically used to check the accuracy of the transducers.

Figure 19. Some transducers come in a protective metal case and do not need to be encased in an additional housing.

Figure 20 illustrates how staff gage readings can be used to check the accuracy of the transducer data over time. The pressure transducer data are compared with the staff gage readings at similar times to determine the offset between the two. If transducer data do not correspond to staff gage data and water depth, the transducer might be fouled, it might need to be recalibrated, or it might need to be resurveyed (Section 3.5). Consult the transducer manual for details on how to calibrate transducers when recorded data are not accurate. If you recalibrate the transducer, record detailed notes on pre- and post-calibration values and changes that were made. If a transducer cannot be calibrated and appears to be recording inaccurate data, contact the manufacturer for further instructions, as it might need to be returned for service.

3.2.2. Sensor configuration and launch

Configure the pressure transducer and data logger to record temperature and pressure every 15 minutes, starting on the hour. This is the same recording interval that is used at USGS gages. Some transducers allow the user to enter an offset value so that logged data are automatically adjusted to the staff gage. If using this option, record the details in the field notebook. Consult the transducer manual for specific details on configuration and launch.

The following practices will make data processing and screening easier and more efficient:

- Set the transducers up so that they start recording on the **hour (xx:00), half hour (xx:30),** or **quarter hour (xx:15 or xx:45).**

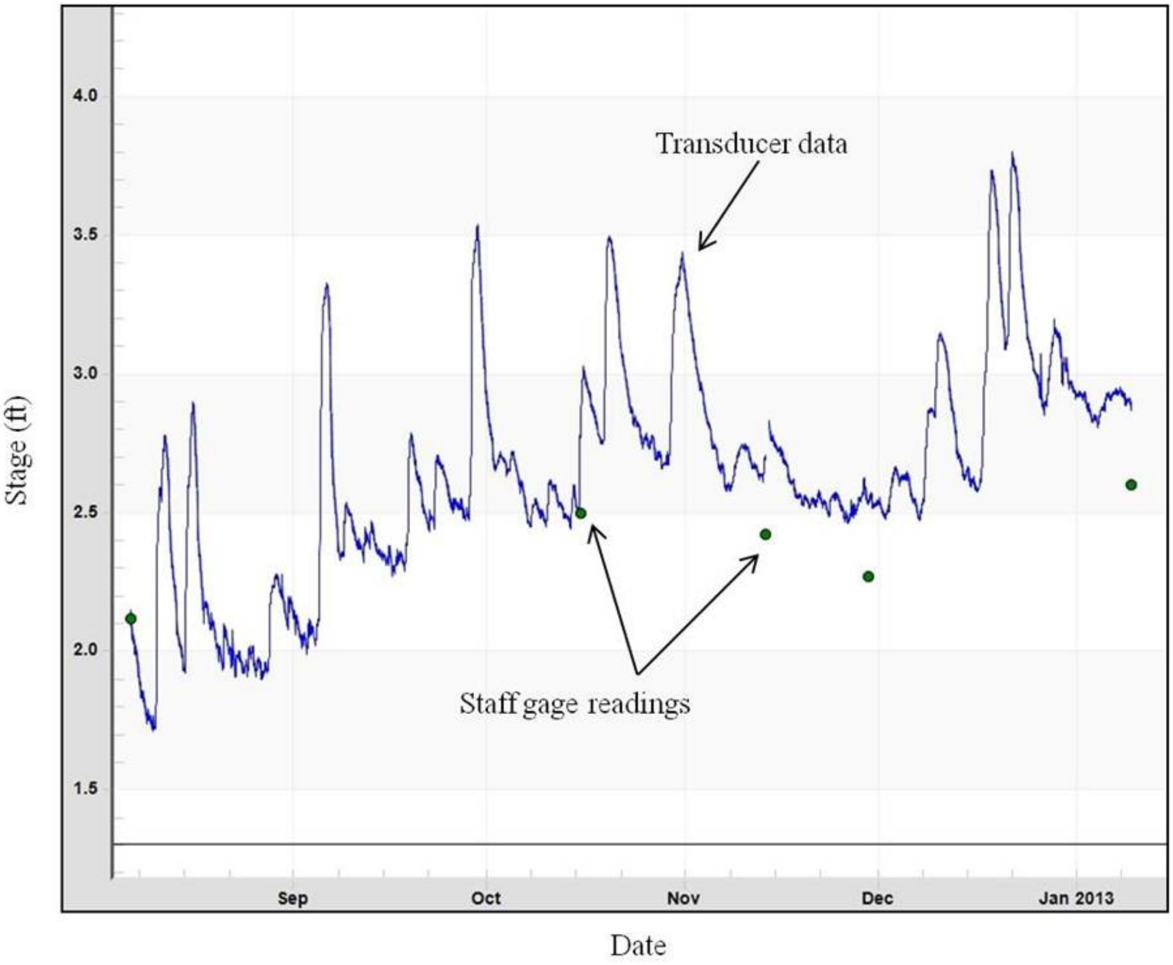


Figure 20. Staff gage readings provide a quality check of transducer data. In this example, staff gage readings stopped matching transducer readings in November, indicating that the transducer or gage could have changed elevation.

- If you are using unvented pressure transducers, set both transducers up so that they **record at the same time.**
- Consider using **military time** (if this is an option) to avoid potential confusion with a.m./p.m..
- Consider using **standard time** (e.g., UTC-5 for sites in the Eastern Time zone) instead of daylight savings time. Regardless of which you choose, make sure that any discrete measurements taken for accuracy checks are consistent with this setting.

Bringing a computer into the field is helpful to launch the transducer and check the logged data once it is installed. Alternatively the transducer may be launched prior to deployment provided you note the date and time of actual deployment in the stream (this is important for data screening; see Section 3.7.2).

3.3. Deployment of Instream Pressure Transducers

Installation of both staff gages and pressure transducers are covered in this section because they are typically installed during the same visit and pressure transducers are sometimes attached to the staff gages. During deployment, safety should always be a consideration, and transducers should only be placed in streams that can be safely accessed and waded by crew members. Install staff gages where they can safely be read at all stages. This might require that you install two sections of a staff gage in different locations (e.g., one in the low flow channel and one in the high flow channel) if the stream experiences a wide range of stages. Prior to installing the equipment, obtain permissions from all relevant parties. This often includes the local Department of Public Works (particularly for bridge installations), the local conservation commission (or equivalent), and abutting property owners if accessing sites will involve crossing private property. Field crews should make efforts to minimize site impacts.

3.3.1. Selecting a location

Prior to gage and transducer installation, conduct a site reconnaissance survey to identify suitable stretches of river for installation. At some sites, natural streambed installations will be most appropriate, while at others, attaching equipment to built structures like bridges might be best. During the site visit, determine what type of installation is best so that appropriate equipment can be obtained prior to installation. If the transducer is collecting data that are representative of the characteristics of the reach from which the biological data are being collected, the transducer does not have to be located in the exact area where the biological data are being collected (e.g., perhaps the best attachment point for the transducer is a bridge or other built structure, and the biological sample is collected 200 meters upstream from the bridge).

Key considerations for siting instream transducers are listed below. These considerations are similar to those for water temperature sensors (see Section 2.3.1). More detailed information on site selection and controls can be found in Rantz et al. (1982).

- The water level data should be representative of the characteristics of the reach from which the biological data were collected. Note that for general monitoring purposes, the sensor need not be placed in the exact location where biological data are being collected.
- Ensure that the site is not in the immediate vicinity of tributaries entering the river, and that no water is entering or exiting between the pressure transducer and the biological sampling site (e.g., through tributaries, pumping, or diversions). The goal is to minimize potential impacts from backwater during high flows (tributary downstream) or unevenly distributed streamflow across the channel (tributary upstream).
- The gaging equipment should be installed in a pool where turbulence is minimal to increase accuracy of gage and transducer readings. The pool should have a downstream control feature that allows for stable stage measurements and ensures that the equipment will be submerged during low flows (Figure 21, Rantz et al. 1982). Natural controls might include a downstream riffle, bedrock outcrop, or other stream feature that controls flow. Unnatural controls might include a bridge or culvert that is narrower than the stream channel and constricts flow. Note that the feature controlling the stage-discharge relationship can change at different flow levels; such changes will be reflected in the rating curve.

- The site should not have extensive aquatic vegetation, beaver activity, or unstable streambeds and banks. These factors can change or result in unstable stage measurements.

Figure 21. Examples of controls downstream of staff gages include A. riffle and B. culvert.

3.3.2. Staff gage installation

Staff gages and pressure transducers are typically installed during the same site visit, and transducers are sometimes attached to the staff gages. Staff gages can be attached to a fixed object in the stream (e.g., bridge, boulder, or weir) or installed in the streambed (Figure 22). If suitable conditions are present and proper equipment is available, attaching gages to a bridge or other fixed structure is preferable, as this minimizes the chance that the gage will shift in high flows or in the presence of large debris. The streambed installation method works best in smaller, higher order streams that do not experience extreme high flows that could knock over the gage. A list of equipment needed for installation is in Table 16.

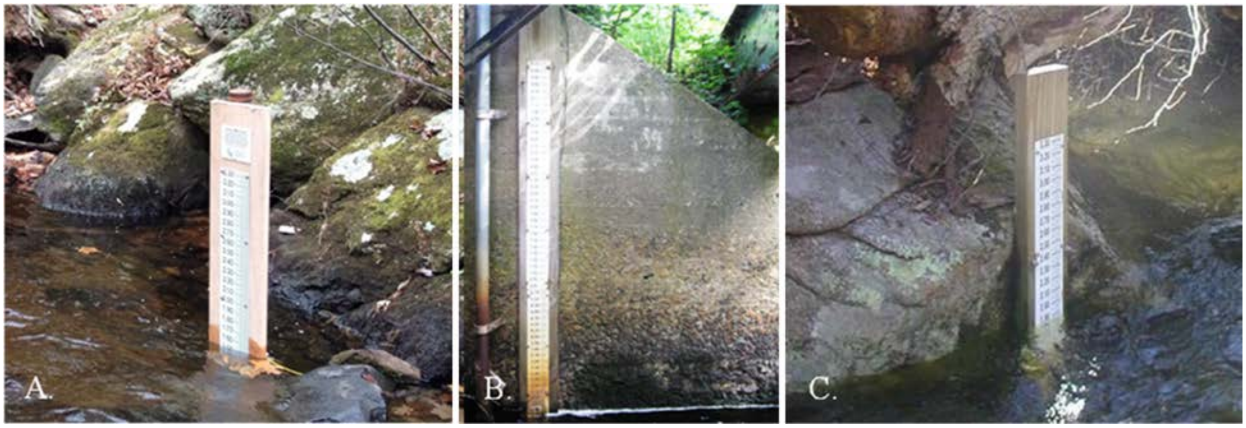


Figure 22. Examples of gage installation techniques include A. streambed, B. fixed object – bridge wing wall, and C. fixed object – boulder.

Table 16. Equipment list for staff gage installation

Location	Supply list
All	• Staff gage • Gage board • Screws (stainless steel or brass) • Screwdriver • Assorted drill bits for wood • Level • Stepladder (if installing more than one section of a staff gage) • Datasheets and field notebook • Survey equipment (auto level or laser level and stadia rod, paint marker or nails for marking benchmarks)
Fixed Object – additional items	• Concrete wedge anchor and nuts (stainless steel or galvanized) • Hammer or rotary drill • Concrete drill bit • Hammer
Streambed – additional items	• Galvanized or stainless steel pole with cap • Galvanized or stainless steel conduit straps • Pole driver or sledge hammer • Pry bar

Gages are typically available in 3.33-foot sections; multiple gage sections can be combined to encompass the entire range of stages expected to occur in that section of the stream (additional sections can be added if the river tends to rise higher than expected). Stream gages should be attached to a board that is at least as high and wide as the gage and able to withstand being submerged in water (good materials include oak, plastic wood, or pressure-treated wood). Use screws and a level to attach the gage to the board. Care should be taken to level the combined board/gage before it is attached to the fixed object or pole.

For fixed object installations, the gage and board are directly attached to a bridge or other permanent structure, using the following procedure:

- Level the gage board on the fixed object and mark locations for concrete wedge anchors (Figure 23). Use concrete anchors on both sides of the board and at varying elevations to ensure the board's stability. Two anchors are typically sufficient for a 3-foot gage and three for a 6-foot gage.
- Use a hammer drill or rotary hammer with a concrete drill bit to drill holes in the marked locations.
- Pound concrete wedge anchors (bolts) into the holes using a hammer until they are secure.
- Drill holes in the gage board for concrete wedge anchors.

Place the board over the bolts and screw it into place using the nut.

For streambed installations, the gage and board are attached to a pole that has been driven into the streambed, using the following procedure:

Figure 23. Example of a 0.5-inch by 3.75-inch wedge anchor with bolt and washer.

- Use a pry bar to test the streambed in the pool for locations where the pole can be driven into the bed.
- Drive a galvanized steel pipe with cap into the streambed using a pole (fencepost) driver or sledgehammer. Poles of 6 feet and 9 feet are generally sufficient for 3.33-foot and 6.66-foot gages, respectively. The pole should be driven into the streambed at least 3 feet or until it is very stable and unlikely to be knocked over in high flows. The pole should be as straight as possible so that when the board and gage are attached, they can be leveled. A step ladder can be helpful for driving the pole.
- Attach the combined board/gage to the pole using galvanized or stainless steel conduit straps (use at least two for a 3.33-foot gage). The board should be parallel to the flow and, if possible, positioned so that it can be read from the stream banks.

If a tree is nearby on the stream bank, a metal bracket or brace can be attached from the gage to the tree to increase stability.

3.3.3. Pressure transducer installations

This document describes two installation techniques for pressure transducers: the fixed object method, in which the transducer is attached vertically to the staff gage board or to an object like a bridge, boulder, or weir; and the streambed method, in which the transducer is laid horizontally on the streambed and is held in place by rebar and rocks. Site-specific conditions dictate which technique is most appropriate.

3.3.3.1. Fixed object

With the fixed object installation, the pressure transducer is attached vertically to the staff gage board or to an object like a bridge or boulder. Before the pressure transducer can be attached to the fixed object, it must be enclosed in a protective housing (Section 3.1.4). For vented transducers, which do not need to be removed from the stream to download data, the housing should be cut to a length at least slightly longer than the transducer. If PVC pipe is used, attach the transducer to the housing with heavy-duty zip ties to ensure it does not move (Figure 24). Do not leave slack in the zip ties. If the unit can move, it can wear through the zip tie.

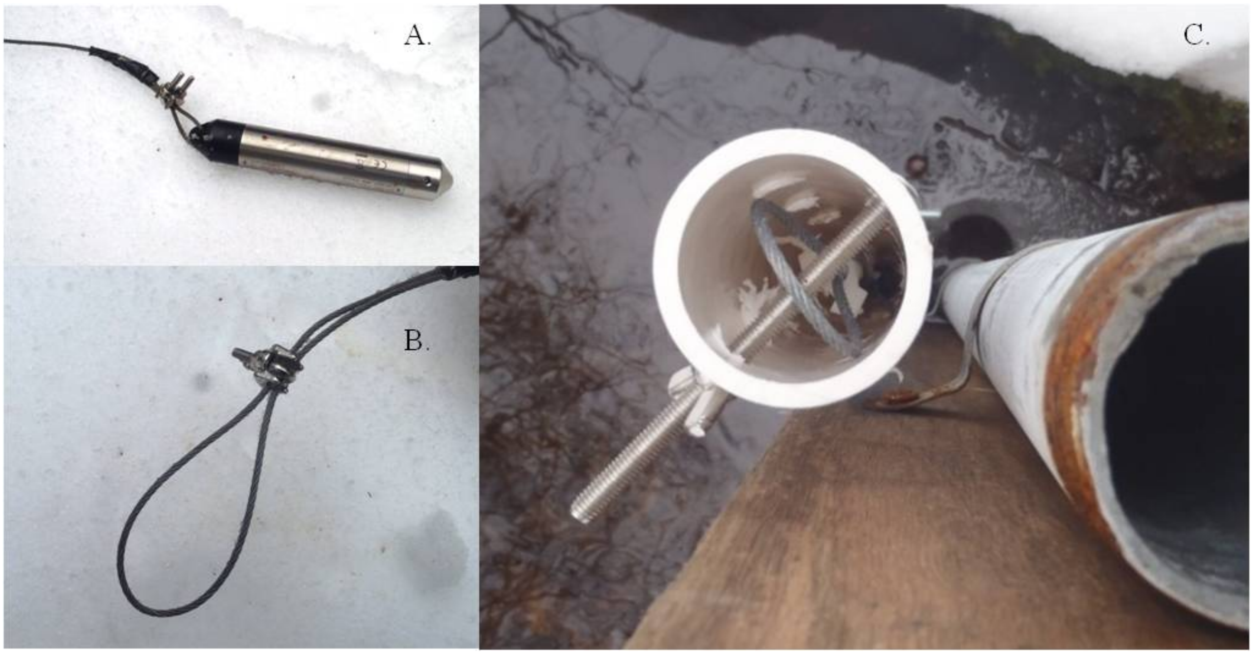


Figure 24. Non-vented pressure transducer installation. A. Non-stretch cable is attached to the transducer, B. A loop is made at the non-transducer end of the cable, C. A cable with transducer is suspended over the bolt from the top of the PVC pipe.

Non-vented pressure transducers typically should be removed from the stream to download data. To facilitate data removal and downloading during high water periods, install the transducer into a PVC pipe as follows:

- Use a PVC pipe that is approximately the same height as the gage board.
- Attach a non-stretch cable or rope (e.g., coated stainless steel cable) to the transducer and make a loop at the non-transducer end (Figure 24). The cable should be long enough that the transducer will always be under water but not so long that it will come into contact with the streambed.
- Place the looped cable over a long bolt with a wing nut that runs through the top of the PVC (Figure 24). Clearly mark the holes for the bolt so that the transducer is placed back at the same elevation every time it is removed.

Once the pressure transducer has been installed in the protective housing, the transducer/housing can be attached vertically to the staff gage board (Figure 25), a bridge abutment, or fixed object, or horizontally to rebar or other pipe in the stream bed. An equipment list for installations is found in Table 17.

Figure 25. Non-vented (left) and vented (right) pressure transducers attached to staff gage board using conduit hangars.

Table 17. Equipment list for transducer installation

Location	Supply list
All (continued)	• PVC pipe for transducer (drilled with 1/2-in or larger holes) • PVC pipe for data logger or barometric pressure logger • Galvanized or stainless steel conduit straps, hangars, and hose clamps • Zip ties/cable ties • Screws (stainless steel or brass) • Screwdriver • Drill • Assorted drill bits for wood and PVC • Level • Datasheets and field notebook • Survey equipment (see Section 3.3.5)

Table 17. Equipment list for transducer installation (continued)

Location	Supply list
	If using a non-vented transducer, you also need: • Non-stretch cable or wire • Wire rope clamps • Long bolt and wing nut • Extra-long PVC (should extend out of water in high flows) • Solar shield (if using barometric logger for air temperature data, see Appendix B for instructions) • PVC with caps for barometric transducer If using a vented transducer, you also need: • Garden staples • PVC pipe for data logger • PVC cap or locking well cap • Stainless steel conduit straps • Long lag screws • Wire cable • Replacement desiccant (if necessary)
Fixed object – additional items	• Hammer or rotary drill • Concrete drill bit • Concrete wedge anchor and nuts (stainless steel or galvanized) • Hammer

To install the transducer/housing on a staff gage board:

- Place the PVC pipe with transducer on the downstream side of the board directly next to the galvanized steel pole, or whichever side is the least turbulent.
- Attach the PVC pipe to the board vertically using galvanized or stainless steel conduit straps or hangars.
- Ensure that the PVC pipe and transducer are installed slightly above the streambed to reduce chances of fouling by fine sediments.

To install the transducer/housing on a fixed object (e.g., bridge abutment):

- Install the transducer close to the staff gage so that stage changes are comparable.
- Use concrete anchors and conduit straps, hangars, or hose clamps to attach the PVC vertically to a bridge or boulder.
- Ensure that the PVC pipe and transducer are installed slightly above the streambed to reduce chances of fouling by fine sediments.

3.3.3.2. Streambed/rebar

With the streambed installation, the transducer is laid horizontally on the streambed and is held in place by rebar and rocks (Figure 26). Compared to the fixed object method, transducers are more prone to moving or being swept away during high flows, and ensuring that transducers are returned to the exact same location after being removed for data downloads can be more difficult.

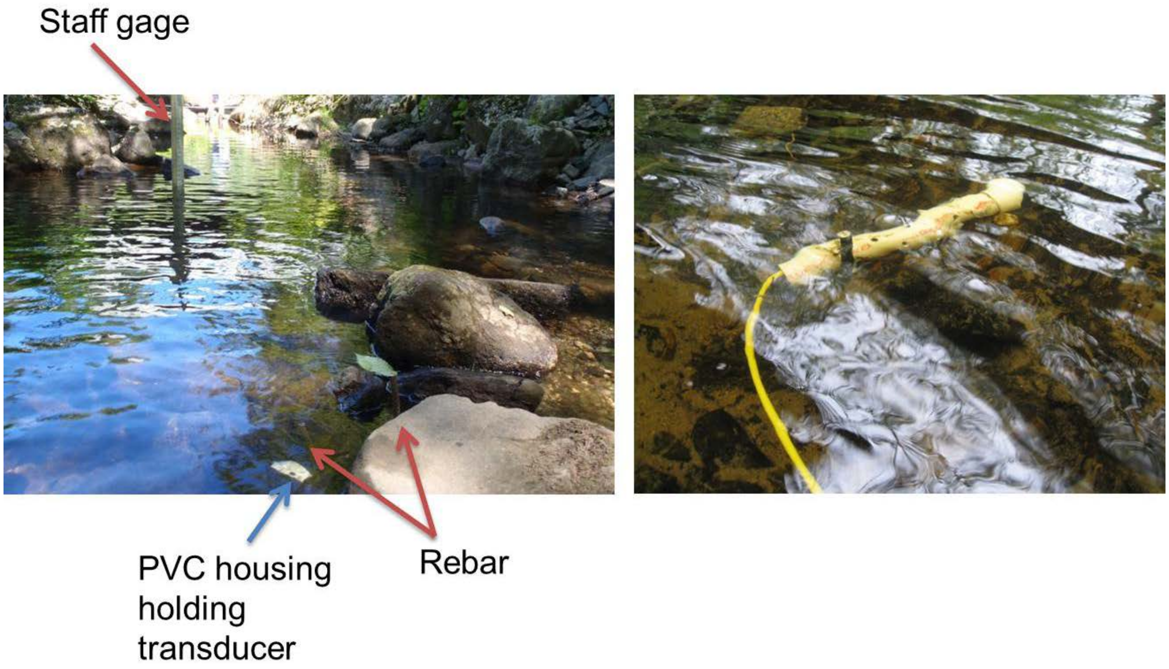


Figure 26. Examples of streambed installations of pressure transducers using rebar.

Streambed installations require rebar stakes and a sledgehammer in addition to the equipment listed in Table 16. Installation instructions are as follows:

- Find a pool location close to the staff gage and protected from turbulence and debris (behind a large rock is ideal).
- Drive two rebar stakes into the ground (spaced apart slightly less than the length of the PVC housing).
- Use cable ties or steel hose clamps to attach the PVC to the rebar in a relatively horizontal position.
- For added stability, pin the PVC pipe between the rebar and the rock, or place large rocks over the PVC pipe, or do both.
- Ensure that the PVC pipe and transducer are installed slightly above the streambed to reduce chances of fouling by fine sediments.

3.4. Deployment of On-Land Components

Both vented and non-vented transducers have components that must be installed on land. Vented transducers are typically connected to data loggers on land via a vented cable. When using non-vented transducers, a separate, identical transducer must be deployed on land to measure barometric pressure. This section describes a general installation approach for both components and concludes with specific considerations for data loggers and for barometric pressure sensors.

Both devices should be located well above where high flows or the snow pack will reach, but not so high that they are inaccessible for data downloads. Trees are generally the most suitable attachment points for these devices. If no trees are present, install a stainless steel pole (with a cap) and attach the data logger to it. Use the same type of pole used for the streambed staff gage installations. Hide the devices from view to reduce the chance of vandalism.

The devices should be encased in a PVC pipe. The device may sit on the bottom of the pipe or be suspended on a wire or cable. If the data logger is not supported by the PVC pipe, suspend it on a wire or cable so no pressure is placed on the vented cable. Leave enough slack in the data logger cable to allow the logger to be lifted slightly out of the PVC pipe to download data.

Installation instructions are as follows:

- Attach a PVC pipe to a fixed object on the bank. The pipe can be attached to a tree with U-shaped conduit straps and long screws or zip ties (Figure 27). Adjust the length of the pipe to adequately cover the device with some extra room.

Figure 27. Vented transducer data logger installation. The transducer is attached to the tree with stainless steel conduit straps.

- Place the device inside the PVC pipe.
- Place a PVC cap or a locking well cap on top of the PVC pipe to protect the equipment and discourage vandalism.

Specific considerations for the data logger include:

- For vented transducers with excess cable, coil the cable and zip tie it to the tree or PVC pipe.
- Use garden staples (4-inch U-shaped steel staples), rocks, and leaf litter to hide the data logger cable. For extra protection, the cable can be encased in a PVC pipe.

Specific considerations for the barometric pressure sensor include:

- Place the device as close as possible to the instream pressure transducer.
- The PVC housing should be drilled with holes to facilitate air flow (similar to those used to protect the instream pressure transducer [Figure 28]).

Figure 28. Barometric pressure sensor installation for a non-vented transducer, A. without the PVC cap and B. with the PVC cap. Holes should be drilled into the bottom cup of the PVC housing. This prevents condensation and laterally blown rain and snow from filling the cup to a depth sufficient to inundate the ports through which the barometric pressure is compensated. Another option is to deploy the barometric pressure sensor upside down, so that the port tip is on top.

- Holes should also be drilled in the bottom of the PVC housing to prevent condensation and laterally blown rain and snow from filling the cup to a depth sufficient to inundate the ports through which the barometric pressure is compensated. If this occurs, the “barometric pressure” becomes barometric pressure plus a small amount of pressure due to this accumulated water, and the data cannot be used. This issue can also be addressed by deploying the barometric pressure sensor upside down, so that the port tip is on top.

3.5. Elevation Surveys and Documentation

After the installation is complete, georeference and document the pressure transducer location in a way that enables field personnel to relocate the sensor during subsequent visits. Take photographs from different perspectives (e.g., upstream and downstream); photos are important for relocating the transducers and documenting changes to the monitoring location during the course of the study. Record all documentation information on a field form that includes information such as station number, waterbody name, date, time, crew members, driving directions, serial number/s of transducer/s, time of deployment, transducer installation technique, image numbers/file names for the photographs, and detailed descriptions of transducer placement. Be sure to record the time and date of deployment accurately, as this information will be used in the error screening procedure described in Section 3.7.2.

In addition, survey the elevation of the staff gage and pressure transducer to establish a reference point for the gage and transducer. This allows for monitoring of changes in the location of the transducer, which is important because if the transducer moves, stage data will be affected and corrections will need to be applied. If possible, conduct elevation surveys at least once a year to identify if and when movement occurs. This is particularly important after high flow events and periods of extended ice cover. Steps for conducting elevation surveys using an auto level are summarized in Table 18, and Table 19 contains a list of equipment needs. For additional information on surveying techniques see Harrelson et al. 1994.

Table 18. Quick guide for elevation surveys of staff gages and transducers using an auto level

Procedure
1. Set up tripod and auto level in location where you can view benchmark and all survey points. Level auto level by centering the level bubble using the foot screws. 2. Have person hold stadia rod on top of benchmark. Rod must be level. 3. Read elevation at which crosshairs in auto level cross the stadia rod. 4. Record this elevation as the starting backsite (B.S.). 5. Have person hold stadia rod on survey point #1. Rod must be level. 6. Read elevation at which crosshairs in auto level cross the stadia rod. 7. Record this elevation as the foresite (F.S.). 8. Repeat steps 6 to 8 for additional survey points (including the top of the staff gage and transducer). 9. Have person hold stadia rod on top of benchmark. Rod must be level. 10. Read elevation at which crosshairs in auto level cross the stadia rod and record as final B.S. 11. If final B.S. does not match starting B.S. (within 0.01 ft), repeat the entire survey.

Table 19. Equipment list for elevation surveys

Supply list
• Auto level or laser level • Tripod • Stadia rod • Survey paint • Survey nails • Datasheet

Perform the elevation survey on the day of staff gage and transducer installation. Identify and establish a benchmark and one or two other permanent markers at the site. The benchmark will serve as the predominant reference point for the gage/transducer; the additional permanent marker(s) provide a backup in case the benchmark is destroyed and allows for a check of benchmark movement. Knowing the absolute elevation of the benchmark is unnecessary as the purpose is to detect changes in elevation of the equipment relative to the benchmark. The benchmark therefore can be given a relative elevation (e.g., 100 feet) as part of the calculations. Reliable permanent markers can be found on bridges and other permanent structures (e.g., a specific corner on a part of the bridge structure) (Figure 29); nails in trees are less stable but a good alternative in relatively secluded sites. Boulders should be used only if they are very unlikely to shift and if a clear point on the boulder can be identified and marked with survey paint. All permanent markers should be visible and accessible during all expected stream stages and vegetation covers.

Figure 29. Examples of auto level and tripod used for elevation survey (A) and permanent structure used as a benchmark (B).

Once markers are established, sketch their location on the data sheet (see example in Figure 30), clearly documenting both markers and relevant site features that can be used to locate the markers in subsequent surveys. Take pictures of the benchmark with clear identifying features. Survey the benchmark, permanent marker(s), and gage and transducer elevations, repeating the survey of the benchmark after all other points (see Table 18). If the benchmark height is different at the end of the survey compared to the beginning, repeat the entire survey. For surveying the staff gage, hold the stadia rod on the top of the metal gage (not the board). For surveying the transducer, make clear notes of where the stadia rod was placed on the PVC pipe (e.g., top, river right, river left). Calculate the elevations of all points relative to the benchmark using the following equations:

$$\text{Height of instrument (H.I.)} = \text{Backsite (B.S.)} + \text{Elevation of benchmark (B.M.)}$$

$$\text{Elevation of survey point} = \text{H.I.} - \text{Foresite (F.S.)},$$

where B.S. is the height of the stadia rod at the benchmark and F.S. is the height of the stadia rod at each survey point (e.g., permanent marker, top of gage, transducer housing) and the elevation of benchmark is the relative elevation (e.g., 100 feet). To calculate the actual elevation of the transducer, subtract the distance from the transducer housing (at the point where the stadia rod was placed) to the sensor face from the elevation of the transducer housing.

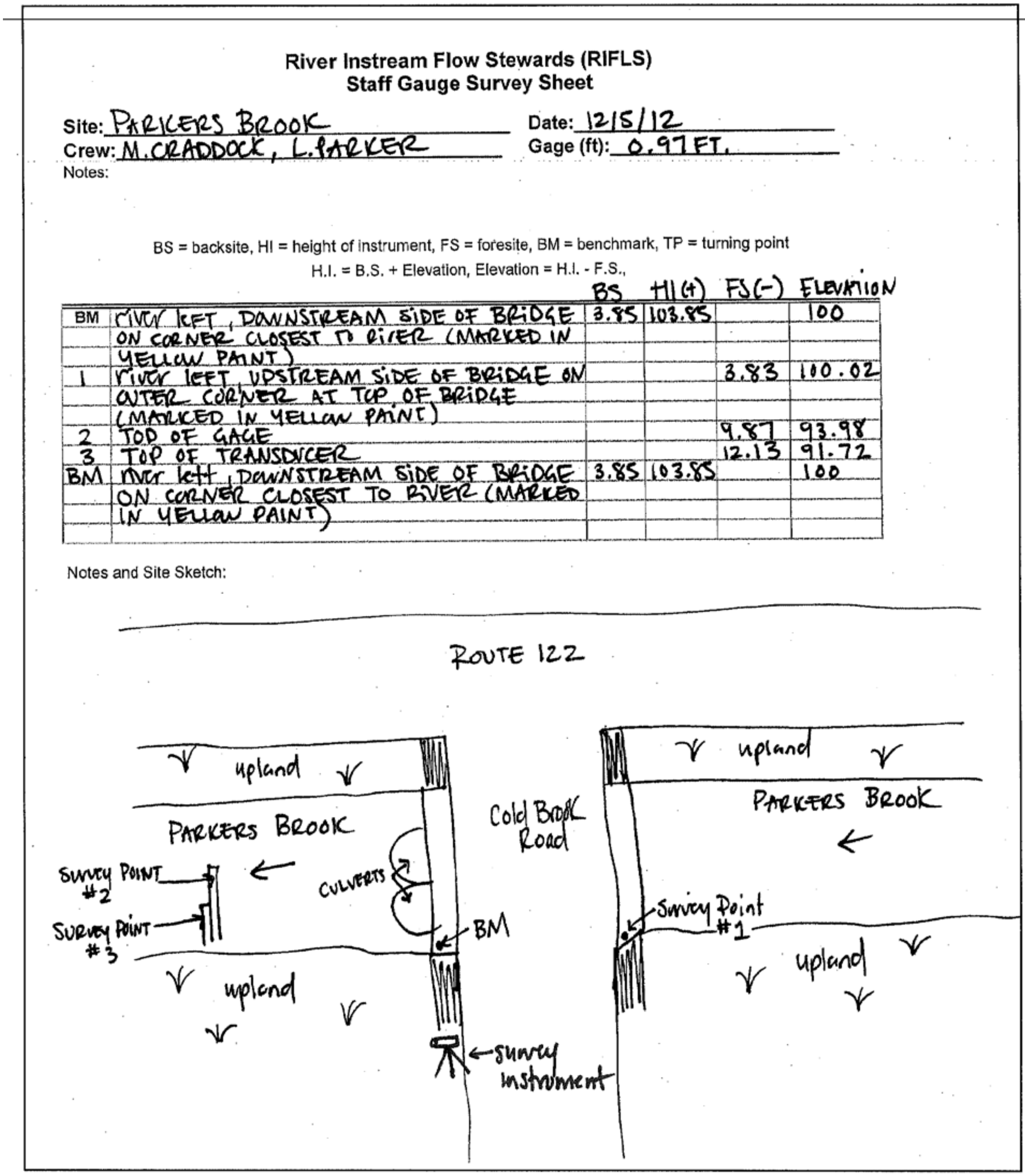
After elevations of all survey points are calculated, compare beginning and end H.I. to ensure no movement of the auto level during the survey. Next, compare elevation of all survey points to previously surveyed elevations to determine if movement occurred.

3.6. Maintenance/Mid-Deployment Checks and Data Offload

After a transducer is installed at a site, try to revisit the site within the first month to confirm that the installation is holding properly. After these initial deployment checks, at a minimum, visit sites annually (e.g., in conjunction with the biological sampling events). More frequent visits are encouraged, however, particularly to check for movement of the staff gage and transducer after high flow events and periods of extended ice cover. More frequent site visits will help ensure the longevity of gaging stations and data quality.

During site visits, field personnel should:

- Check the condition of the transducer and perform necessary maintenance.
- Take staff gage readings or measure the depth of water over the transducer with a stadia rod or other measuring device, ideally at different flow conditions, to check the accuracy of the transducer data. To minimize the chance of a faulty measurement, take the measurement as close as possible to the time that the pressure transducer is recording a measurement, and get as stable a reading as possible (if flows are fluctuating rapidly at the time of the measurement, note this on your field form and try to record the depth as accurately as possible). Be sure that no one is standing upstream during these measurements, as this will affect the readings.
- Offload data.



River Instream Flow Stewards (RIFLS)
Staff Gauge Survey Sheet

Site: PARKERS BROOK
Date: 12/5/12
Crew: M. CRADDOCK, L. PARKER
Gage (ft): 0.97 FT.
Notes:

BS = backsite, HI = height of instrument, FS = foresite, BM = benchmark, TP = turning point
H.I. = B.S. + Elevation, Elevation = H.I. - F.S.,

		BS	HI(+)	FS(-)	ELEVATION
BM	river left, DOWNSTREAM SIDE OF BRIDGE ON CORNER CLOSEST TO RIVER (MARKED IN YELLOW PAINT)	3.85	103.85		100
1	river left, UPSTREAM SIDE OF BRIDGE ON OUTER CORNER AT TOP OF BRIDGE (MARKED IN YELLOW PAINT)			3.83	100.02
2	TOP OF GAGE			9.87	93.98
3	TOP OF TRANSDUCER			12.13	91.72
BM	river left, DOWNSTREAM SIDE OF BRIDGE ON CORNER CLOSEST TO RIVER (MARKED IN YELLOW PAINT)	3.85	103.85		100

Notes and Site Sketch:

Figure 30. An example of a completed elevation survey form.

Typical maintenance issues include:

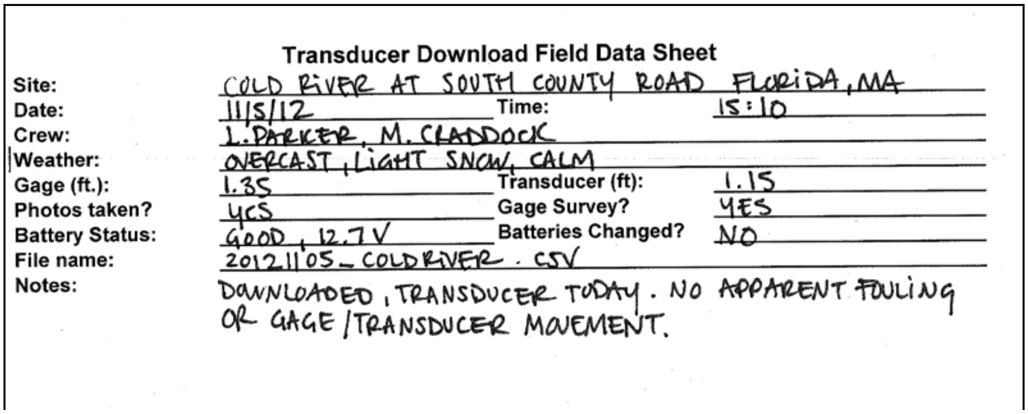
- Ensuring that the instream pressure transducer is *submerged and not buried in sediment.*
- *Clearing leaf litter and debris* that might pile up against the gage, transducer, and downstream control. At the beginning of a site visit, clear this material as it could impact gage height. Note the stage before and after debris clearing to check for any changes. Stage data may be corrected if changes are detected.
- *Checking for transducer and staff gage movement after high flows and floods*. The difference in elevation between the staff gage and the transducer can change if sediment accumulation or scour occur near the gage and transducer. If movement is detected, secure the equipment (if necessary) and resurvey. Note any differences in gage and transducer elevation in a field notebook along with the date and time. If a gage is constantly shifting, consider an alternative location.
- *Checking for impacts from ice cover*. Water temperature and stage data should be evaluated for potential impacts from ice cover and data should be flagged accordingly.
- *Cleaning sediment or algae from the pressure transducers.* These can cause fouling and inaccurate readings. Consult the transducer manual for specific instructions on cleaning and maintenance.
- *Cleaning the staff gage* with a scrub brush, especially during the summer months, so that the gage can be accurately read. For especially dirty gages, baking soda or native sand (if available in situ) can help in cleaning the gage. Paint over any rust marks on the gage with enamel paint to improve durability.
- *Checking the condition of desiccant packets* (vented transducers only). These are needed to keep the vented cable dry. Different transducers use different types of packets, and the lifespan of these packets varies depending on site-specific conditions (e.g., how much moisture is present in the air).

If possible, download data during each site visit. Frequent data downloads, as well as frequent stage measurements from the staff gage, will help in early identification of transducer drift. To download data, a computer and a cable or data shuttle (to connect the transducer to the computer) is typically needed in the field (see Figure 31). Prior to download, record the stage at the staff gage and note any factors that might have affected the data since the previous deployment. After download, spot-check the data for accuracy. If no cleaning or troubleshooting is necessary, re-launch the transducer following procedures outlined in Section 3.2.2. Each time data are downloaded, complete a form like the one shown in Figure 32.

Also check battery life. Batteries in some sensors need to be replaced each year, while others last 5 years or longer under normal use. Plan for these replacements.

Record information from mid-deployment checks in a field notebook or on a field form. That good field notes be taken during every site visit is essential. Entries should include notes about the condition of the transducer, staff gage (or other water level) readings, and whether any unusual measurements appeared during the data spot-check (if available). Taking photos during each site visit is also good practice, as this will help document changes to the monitoring location during the course of the study.

Figure 31. Data download from vented transducer with external data logger on land using computer and cable (left) and non-vented transducer with internal data logger using computer and data shuttle (right).



Transducer Download Field Data Sheet

Site: COLD RIVER AT SOUTH COUNTY ROAD FLORIDA, MA
Date: 11/5/12 **Time:** 15:10
Crew: L. PARKER, M. CRADDOCK
Weather: OVERCAST, LIGHT SNOW, CALM
Gage (ft.): 1.35 **Transducer (ft):** 1.15
Photos taken? YES **Gage Survey?** YES
Battery Status: GOOD, 12.7V **Batteries Changed?** NO
File name: 20121105_COLDRIVER.CSV
Notes: DOWNLOADED, TRANSDUCER TODAY. NO APPARENT FOULING OR GAGE/TRANSDUCER MOVEMENT.

Figure 32. Example of a transducer download field data sheet.

3.7. Quality Assurance and Control

Proper QA/QC is essential to collecting accurate long-term data. The procedures discussed in the following sections will help detect and correct for errors in transducer and stage data.

3.7.1. Accuracy checks

Pressure transducer readings can drift over time, which can result in deviation of transducer data from that observed at the staff gage. As mentioned in Section 3.2.1, making periodic staff gage readings to detect any shift or drift in the transducer data is important. The stage should be recorded every time the site is visited for a discharge measurement or data download. Ideally, gage readings should be done at least every month, if possible, to ensure a variety of stages are captured throughout the deployment period. Frequent gage readings facilitate error screening and early detection and correction of transducer problems that help minimize data loss. If this frequency is not possible due to the remoteness of the field site, local volunteers or other state agency collaborators could assist with gage readings. Local watershed groups or other organizations might be able to help to identify local volunteers. At the minimum, try to visit sites after large storm events, which could impact the transducer.

3.7.2. Error screening

Pressure transducers might record erroneous readings during deployment for a variety of reasons, including:

- they can become dewatered during low flow conditions
- high flow events can bury them in sediment
- high flow events could move them
- they might become fouled from debris, aquatic vegetation, or algae
- humans might cause interference
- they could become encased in ice
- if moisture enters the cable of a vented transducer, it could result in erratic readings or readings of zero water depth
- if the cable of a vented transducer becomes kinked or plugged, it could result in the data not being corrected for barometric pressure

Because these errors may occur, data should be screened. A series of error screening checks is described in Table 20, and Appendix K contains a data screening checklist. Various software applications can be used to help with the error screening checks (e.g., Microsoft Excel, Aquatic Informatics' AQUARIUS (http://aquaticinformatics.com/products), including software that is purchased with the transducers(s)).

The first step in the error screening process involves removing observations recorded before and after the transducer is correctly positioned. 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 transducer to record questionable readings (e.g., during a mid-deployment check, the transducer was found to be buried in the sand) and flag those data accordingly.

Next, plot all of the measurements and visually check the data**.** Look for missing data, outliers and other abnormalities, Specific errors to watch for include: missing data; values of 0 **(**which could mean that the pressure transducer was dewatered, or in the case of vented transducers, could mean that moisture entered the cable); values flat-lining at 0°C/32°F (the stream pressure transducer is likely encased in ice); negative values **(**if unvented transducers are being used, this could indicate that the barometric pressure correction is off); and outliers or rapidly fluctuating values (the stream pressure transducer could have moved (e.g., due to a high flow event or vandalism). Also consider performing the following additional checks: graphically compare data

Table 20. General summary of different types of problems that can occur with pressure transducer data and recommended actions for addressing them

Problem	Recommended action
Missing data	Leave blank
Stream pressure transducer was dewatered or buried in sediment for part of the deployment period	Use the plot (and temperature data, if available) to determine the period during which the problem occurred. Exclude these data when calculating summary statistics.
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.
Drift is large and when and how much the sensor was 'off' cannot be determined (when drift occurs, the difference between staff gage or depth readings and pressure transducer readings increases over time)	The data should be removed.
Discrepancy between pressure transducer reading and discrete measurement taken during a staff gage or depth check	General rules: • If the errors are smaller than the 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, and include the data in summary statistics calculations. • If the transducer fails a staff gage or depth 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 gage measurement (Were flows fluctuating rapidly at the time of the measurement?). Also check whether the same time setting was used for both the transducer and gage or depth measurements (daylight savings time vs. standard time). Based on this information, use your best judgment to decide which action (leave as is, apply correction, or remove) is most appropriate.
A shift is detected and an elevation survey reveals that the stream pressure transducer has moved	Stage readings can be adjusted by adding or subtracting the difference in elevation. If the exact date of the elevation change is unknown, compare gage data to transducer data to observe any shifts. If no gage data for the time period are available, transducer data should be examined for any sudden shifts in stage. Changes in the elevation typically occur during high flows, so closely examine all data during these time periods.
The sensitivity of the pressure transducer changes with stage (e.g., the transducer is less sensitive or accurate at high stages)	Sensitivity drift can be detected by graphing the difference between transducer and staff gage readings against the gage height and plotting a linear trend line through it. A strong correlation between the data sets and a positive or negative trend line as stage increases or decreases could indicate a sensitivity shift. Based on this information, use your best judgment to decide which action (leave as is, apply correction, or remove) is most appropriate.

across years (when data from one year are dramatically different, errors might be present); graphically compare with precipitation data from the nearest active weather station; and graphically compare with data from the nearest USGS stream gage, if appropriate. If discrepancies occur, use the plots to specify the time and duration of errors in the raw data files.

Additional checks (e.g., for accuracy and drift) are described in Table K1 and Appendix K. If you are inexperienced at addressing errors with continuous stage data, consider seeking guidance from someone with more experience and consult references like Wagner et al. (2006). Table 20 provides a general summary of different types of problems that can occur (e.g., missing data, failed accuracy check) and recommended actions for addressing them. Corrections should not be made unless the cause(s) of error(s) can be validated or explained in the field notes or by comparison with information from nearby stations.

Any changes or corrections that are made to the data should be noted, and both the original and the “cleaned” data files should be maintained and backed up. Large amounts of data will accumulate quickly so a central database should be developed and maintained from the initial stages of monitoring. Also, all field forms should be organized, easily accessible, and archived in a way that allows for safe, long-term storage. Accurate field notes and accuracy check logs are essential in the data correction process.

3.8. Developing Stage-Discharge Rating Curves

The previous section describes how to install and maintain pressure transducers to measure continuous stage (depth). Taken alone, stage measurements yield some information about streamflow patterns, including the timing, frequency, and duration of high flows (McMahon et al. 2003, Roy et al. 2005). Stage data per se, however, do not provide quantitative information about the magnitude of streamflows or flow volume, which makes comparing data between streams difficult. Furthermore, the channel shape can change from year to year, such that a similar stage measured in a given location during two separate years could represent different flows. Thus, to assess patterns and changes in stream hydrology, converting stage measurements into streamflow is most useful. Different approaches are available for converting stage to discharge. The most common approach is to develop a stage-discharge rating curve, which we present here.

A rating curve enables the user to convert stage measurements to streamflow. To develop a rating curve, a series of discharge (streamflow) measurements is made at a variety of stages, covering as wide a range of flows as possible. In this section, we briefly describe how to take discharge measurements in wadeable streams. This involves measuring the depth and velocity of the water passing through several segments along a given cross-section of stream. Each measured velocity is multiplied by its contributing flow area; the resulting flows are summed across the cross-section to produce a total flow. A full treatment of this topic is beyond the scope of this document. For more detailed guidance consult Rantz et al. (1982), Chase (2005), or Shedd (2011).

3.8.1. When to measure discharge

Five to ten discharge measurements should be made to establish a rating curve at a new site. To construct a rating curve that accurately predicts flow under most conditions, take measurements over as wide a range of flows as possible. After establishing a rating curve, measure discharge at least once annually, and if possible, also after large storms or any other potentially channel-disturbing activities, to verify or (if needed) update the curve (see Figure 33. for an example of a channel-disturbing activity). If new measurements are more than 15% off the rating curve, follow-up measurements should be made to identify whether a shift has occurred and, if necessary, to establish a new rating curve.

Figure 33. A culvert replacement downstream of a stream gage on Gulf Brook in Pepperell, MA caused enough of a channel change to necessitate a new rating curve.

3.8.2. Equipment

This section covers measuring discharge using current meters, which is generally the most low-cost approach (compared to using acoustic doppler-based instruments, for example). The basic equipment includes:

- **Current meters** measure point velocity. Many different types are available, including mechanical meters (e.g., Price and Pygmy meters, which are vertical-axis meters) and electromagnetic meters (e.g., Hach/Marsh-McBirney).
- **Wading rods** are used to measure water depth at verticals and to set the current meter at the appropriate depth.
- **A measuring tape and stakes** are used to define the exact location of the cross section at which depth and velocity are measured.

3.8.3. Site selection

Site selection is critical for making a good discharge measurement. An ideal cross section will have the following characteristics (see Figure 34 for examples):

- A relatively straight stream channel with defined edges and a fairly uniform shape
- Limited vegetative growth, large cobbles, and boulders

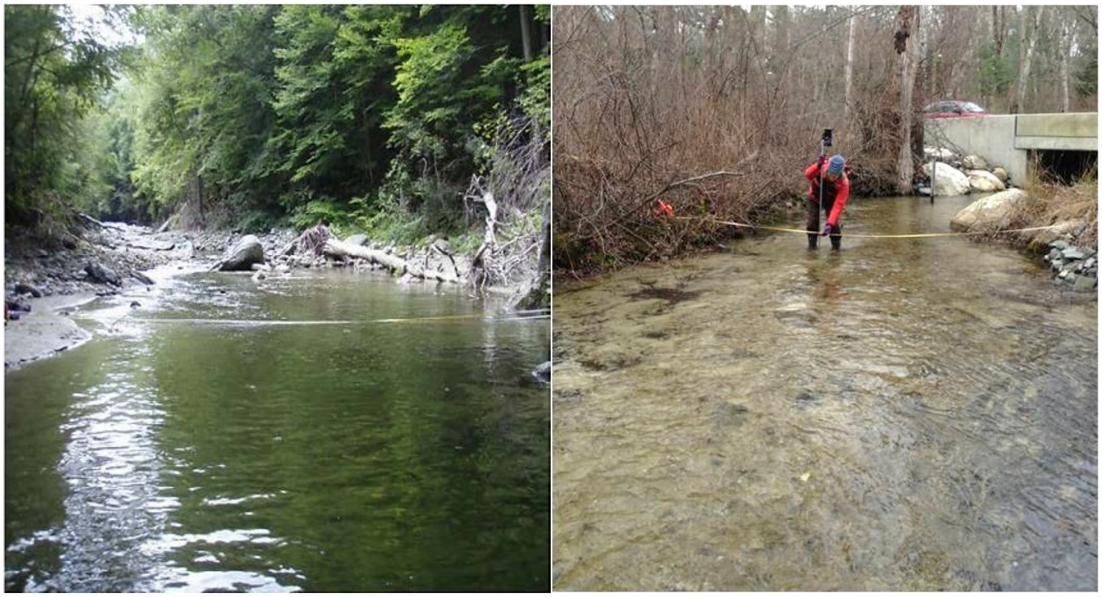


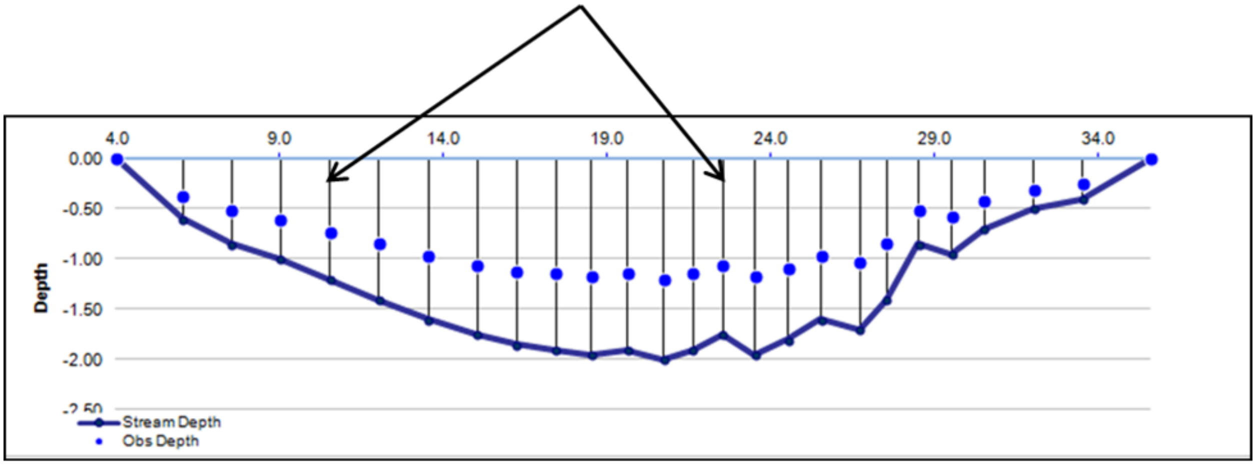
Figure 34. Examples of good cross-sections for making discharge measurements.

- No eddies, slack water, or turbulence
- Depths greater than 0.5 feet and velocities greater than 0.5 feet per second
- Similar flow to that at the gaging station (e.g., no tributaries or drainpipes should be located between the cross section and the gaging station)

Meeting all of these criteria is often not possible (neither cross-section depicted in Figure 34 is perfect). Some minor alterations of the streambed, such as removing excessive aquatic plants or large rocks, can significantly improve the quality of a cross section. Rocks can also be moved to create a more defined stream edge. All such changes must be made before starting measurements. The location of the "best" cross section will likely vary depending on flow conditions. Often a culvert or bridge meets many of the above criteria and provides a good location to measure flow.

3.8.4. Measurements

Streamflow is calculated by summing individual discharge measurements at numerous segments of the cross section. A measuring tape (tagline) is stretched across the stream perpendicular to streamflow and anchored at both banks. Distance along the tagline, channel depth, and stream velocity are measured and recorded at a minimum of 20 points along the cross section. Be sure that no one is standing upstream during these measurements, as this will affect the flow readings. Measurement points should be closer together in portions of the cross section where flow is more concentrated and depths are greatest, in order to ensure that no more than 5% of the total discharge passes through any single segment. Measurements may be farther apart where the flow is lowest and depths are shallowest (Figure 35). Include additional segments where velocity or bottom irregularities are the greatest.



Measure distance along tagline, channel depth, and stream velocity at a minimum of 20 points along the cross section.

Figure 35. Layout of a channel cross-section for obtaining discharge data, using the velocity-area procedure.

The exact methodology for making velocity measurements is somewhat specific to the instrument being used. For more details refer to Rantz et al. (1982), Chase (2005), City of Salem (2007), or Shedd (2011), and to instrument manuals.

In addition to measuring streamflow, field personnel should also estimate the gage height of zero flow (GZF), which provides information about the low end of the rating curve. The GZF is the water level at the gage at which the stream would cease flowing. To find it, locate the low flow channel through the hydraulic control downstream of the sensor. Measure the depth of water at the lowest point in the control and subtract that depth from the stage to calculate the GZF. Measuring the GZF at each discharge measurement is best, but locating this point at lower flows might be most practical and effective.

3.8.5. Documentation

At the time of the discharge measurement, take photographs of the staff gage, upstream of the gage, and downstream of the gage. Detailed notes about the discharge measurements should include the following, as applicable:

- Date, weather conditions, field team members
- Start and end times
- Stage at the beginning and end of discharge measurements
- Current meter check (e.g., spin tests for Pygmy/Price)
- Equipment used
- Whether the gage and transducer elevation were surveyed

- Description of the cross section location and characteristics, description of any observed changes that may impact the rating curve or streamflow
- Edge of bank location
- Discharge measured (if calculated automatically by meter), or width, depth, and velocity for each measurement (if calculating discharge in the lab/office)
- Point of zero flow (PZF, if measured) and location of PZF measurement

Examples of discharge datasheets for different flow meters can be found in Appendix J.

3.8.6. Quality assurance and control

As with other parameters, careful attention to QA/QC procedures is necessary to ensure accuracy of discharge measurements. Some good resources for discharge QA/QC include Rantz et al. (1972), Chase (2005), and Shedd (2011). Some major points to keep in mind are as follows:

- Make duplicate measurements, ideally with a different person making each measurement. The measurements may be along the same or different cross-sections. The difference between the two measurements should be less than 15%. Be sure that no one is standing upstream during these measurements, as this will affect the flow readings.
- Periodically check the accuracy of your measurements by making measurements that you can compare to a standard, such as a real-time USGS gage, or to those obtained by an experienced hydrographer from the USGS or another agency.
- Major, channel-disturbing events (e.g., floods, new culverts) can alter the rating curve. If a major event occurs and subsequent points are not aligned with the original rating curve, a new rating curve might need to be developed and used to convert stage to discharge for points following that event.

3.8.7. Making flow rating curves

The rating curve is produced by plotting instantaneous flow measurements and stage heights. They can also be plotted in a basic spreadsheet program such as Microsoft Excel, or using software designed to produce rating curves, such as Aquatic Informatics' AQUARIUS (http://aquaticinformatics.com/products). The curve can include one or more break-points to account for changes in channel morphology at different stages. When drawn on a log-log scale, the rating curve should be a straight line. If the rating curve does not cover the full range of the stage recorded, the curve can be extended to equal twice the highest or half the lowest measurement recorded. For more detail, see Kennedy (1984). An example of a rating curve is shown in Figure 36.

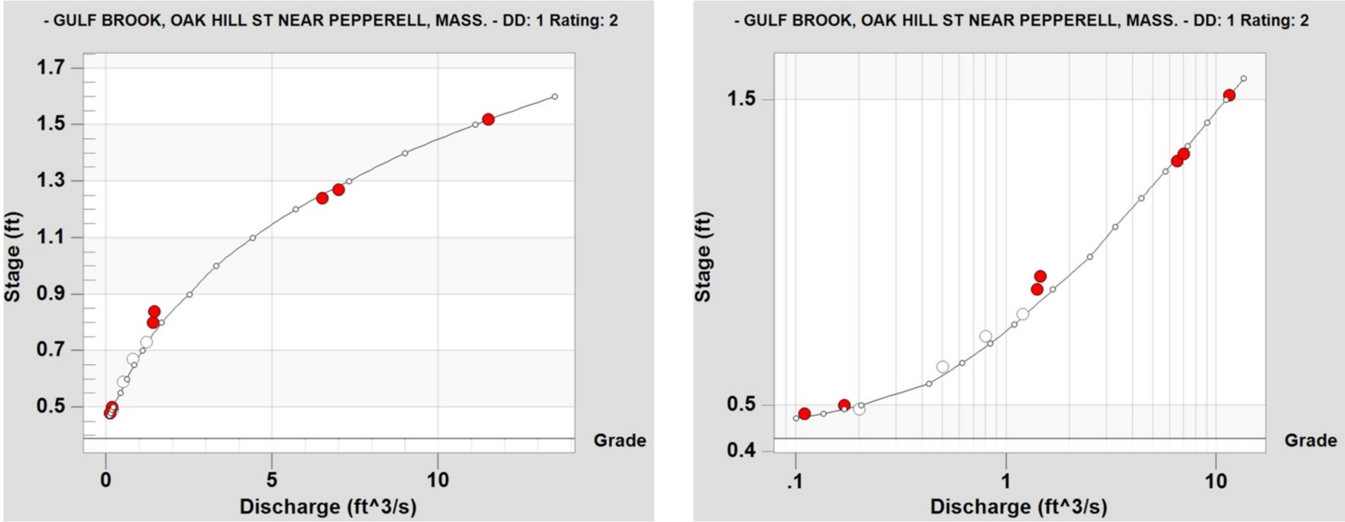


Figure 36. Example of regular (left) and log-log scale (right) rating curves created using Aquatic Informatics' AQUARIUS software.

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