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

NOTICE

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ABSTRACT

The lack of continuous temperature and flow data for minimally disturbed, free-flowing freshwater wadeable streams is an impediment to analyses of long-term trends in biological, thermal, and hydrologic data. In recent years, there has been substantial interest in developing Regional Monitoring Networks with states and EPA Regional offices to detect long-term climate change–related impacts on aquatic communities in freshwater streams. Current participants, including states in the northeast, mid-Atlantic and southeast, are initiating collection of thermal, hydrologic and biological data from targeted sites in each state. To help further this effort, the U.S. EPA and collaborators have written a guidance document to facilitate more uniform and effective collection of continuous temperature and water depth data at ungaged sites in wadeable streams. This document addresses questions related to equipment needs, configuration, placement, installation techniques, data retrieval, and data processing. The collection of these data will further efforts to detect and track climate change–related impacts over the long term, further our understanding of how biological, thermal, and hydrologic conditions vary spatially and temporally and inter-relate to one another, and help inform state and federal agencies on how to attribute altered environmental conditions to climate change versus other stressors.

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LIST OF ABBREVIATIONS AND ACRONYMS

GCIA	Global Change Impacts and Adaptation
GPS	Global Positioning System
NIST	National Institute of Standards & Technology
PVC	Polyvinyl Chloride
PZF	Point of zero flow
RIFLS	River Instream Flow Stewards Program
RMNs	Regional Monitoring Networks
QAPPs	Quality Assurance Project Plans
QAQC	Quality Assurance Quality Control
SOP	Standard Operating Procedures
US 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, and the Global Change Assessment Staff in the Air, Climate, and Energy Program at the U.S. Environmental Protection Agency. It is meant to facilitate 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 lack of continuous temperature and flow data for minimally-disturbed, free-flowing freshwater wadeable streams is an impediment to analyses of long-term trends in biological, thermal, and hydrologic data. To address this, a number of state biomonitoring programs have expressed an interest in incorporating annual monitoring at targeted, minimally disturbed sites into their existing programs, and in coordinating these efforts at a regional level in order to pool resources and increase efficiency. In response, the United States Environmental Protection Agency (US EPA) has been collaborating with its regional offices and states to develop Regional Monitoring Networks (RMNs) to detect changes in stream biota and thermal and hydrologic regimes. This guidance document is meant to facilitate more uniform and effective deployment of continuous temperature sensors and water level sensors at ungaged sites in wadeable streams. It addresses questions related to equipment needs, sensor configuration, sensor placement, installation techniques, data retrieval, and data processing. The data collected through these efforts will further our understanding of how biological, thermal, and hydrologic conditions vary spatially and temporally and inter-relate to one another, and will help inform state and federal agencies and tribes on how to attribute altered environmental conditions to climate change versus other stressors.

The temperature section of this document describes protocols for measuring continuous water and air temperature. At least one water temperature sensor should be deployed at RMN sites. Collection of air temperature data is encouraged as well, since air temperature is an important component of many modeling efforts and can be used to determine if water temperature sensors are dewatered during their deployment. Two installation techniques for water temperature sensors are described: the underwater epoxy method and a method in which cabling is used to attach the sensor to rebar or stable instream structures. After the installation is complete, it is critical that the sensor be accurately geo-referenced and documented in a way that allows field personnel to re-locate it during subsequent visits.

The streamflow section of this document discusses how to install and maintain pressure transducers and staff gages to measure continuous stage (depth). Protocols and methods are based on those used by Massachusetts Division of Ecological Restoration River Instream Flow Stewards program (RIFLS), the United States Geological Survey (USGS), and the Washington Department of Ecology. Pressure transducers record absolute pressure, which software then converts to water level. Data are corrected for barometric pressure. Methodologies for this correction depend on the type of pressure transducer used. Staff gages should be installed at RMN sites because they provide a means to check the accuracy of the transducer data. Procedures for selecting sites, installing pressure transducers and staff gages, surveying their locations and maintaining equipment are covered in the document. In addition, we briefly describe two approaches for converting stage measurements into streamflow: 1) developing a flow rating curve; and 2) modeling flow based on a survey of a cross-sectional profile of the stream. 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, it is most useful to convert stage measurements into streamflow.

After equipment is installed at a site, the site should be revisited within the first month to confirm that the temperature sensor and pressure transducer installations are holding properly. After these initial deployment checks, sites should be visited annually if possible (e.g. in conjunction with the biological sampling events) to check the condition of the sensors, gather data for mid-deployment accuracy checks, and offload data. More frequent visits are encouraged, particularly to check for movement of the staff gage and transducer after high flow events and periods of extended ice cover.

After data are offloaded, quality assurance and control procedures should be performed to verify the quality of the data and to check for potential errors. In this document we describe a series of automated and visual checks that should be performed as a part of quality control procedures for the data. Because large amounts of data will accumulate quickly, a central database should be developed and maintained from the initial stages of monitoring, and all calibration and field forms should be organized, easily accessible, and archived in a way that allows for safe, long-term storage.

1. PUPPOSE AND SCOPE

Few monitoring agencies have collected adequate time-series data to support analyses of long-term trends in biological, thermal, and hydrological data in minimally disturbed, free-flowing freshwater streams (Mazor et al. 2009; Jackson and Fureder 2006; Kennen et al. 2011). Such data are necessary to further our understanding of how conditions vary across sites and over time. Moreover, these data can also inform state and federal agencies on how to assess the relative importance of climate change as a stressor for environmental health. Climate-related impacts are occurring now and are expected to increase. They include rising temperatures, changes in the amount, intensity, frequency, and type of precipitation, alterations in stream flows, and greater risk of droughts and floods (Karl et al. 2009).

To address these needs, a number of state biomonitoring programs have expressed an interest in incorporating annual monitoring at targeted, minimally disturbed sites into their existing programs. Such efforts would ideally be coordinated on a regional level in order to pool resources and increase efficiency. In response, the United States Environmental Protection Agency (US EPA) has been collaborating with states from various regions to develop Regional Monitoring Networks (RMNs) to detect long-term changes in stream biota and thermal and hydrologic regimes. Analyses conducted in collaboration with northeastern states are being used to inform design decisions on sample size, classification, site selection, spatial distribution of sites, indicators, and trend detection time (Bierwagen et al. 2013, in review). Based in part on these analyses, regional working groups are trying to initiate continuous temperature and flow sampling and annual biological sampling at targeted sites in each state. Objectives of these monitoring efforts are to detect climate change–related impacts over the long term, further our understanding of how biological, thermal, and hydrologic conditions vary spatially and temporally and inter-relate to one another, and to inform state and federal agencies on how to attribute altered environmental conditions to climate change versus other stressors.

Year-round temperature monitoring is fundamental to understanding aquatic ecology. Moreover, there is evidence of significant departures in temperature from historical conditions in response to a warming climate (Isaak et al. 2012, Kaushal et al. 2010). Although considerable amounts of stream temperature data are now routinely collected using inexpensive temperature sensors, 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 since it captures a critical time period for most aquatic species' survival. However, summer-only data provides 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.

In addition to temperature, flow regime (magnitude, frequency, duration, timing, and rate of change) also has a strong influence on stream ecology (Poff et al. 1997). The United States Geological Survey (USGS) has been measuring flow in streams since 1889, and currently maintains over 7,000 continuous gages. This large network provides critical, long-term 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). In addition, many of the stream gages deliver data instantaneously through the internet, providing real-time information for a variety of consumers.

At this time, sampling efforts in the RMNs are primarily focused on medium to high-gradient, minimally disturbed headwater and mid-order streams (generally with drainage areas less than 100 square kilometers). Monitoring flow in headwater and mid-order streams is important because streams of this size play a critical role in connecting upland and riparian systems with river systems (Vannote et al. 1980). Not only do they provide sources of water, sediments and biota (Sidle et al. 2000), they are also critical sites for processing organic matter and nutrient cycling (Bilby and Likens, 1980, Wipfli et al. 2007, Clarke et al. 2008). Moreover, small upland streams are likely to experience substantial impacts from climate change (Durance and Ormerod 2007). Headwaters in particular may be vulnerable because their flow dynamics are often closely tied to precipitation patterns. Headwaters may also serve as refugia from the extremes in temperature and flow that are projected to occur (Meyer et al. 2007).

Efforts are being made to co-locate as many RMN sites as possible with active USGS gages since USGS gage data represent the highest quality flow data available. However, many USGS stream gages are located in large rivers that have multiple human uses. Thus, only a limited number are minimally disturbed streams, and in most locations high-quality flow data must be obtained via alternate methods.

The primary purpose of this document is to provide guidance on how to collect accurate, continuous temperature and flow data at ungaged sites in wadeable streams. It addresses questions related to equipment needs, sensor configuration, sensor placement, installation techniques, data retrieval, and data processing. It describes techniques for attaching sensors to natural objects in streambeds, and also covers installations in which sensors are attached to man-made structures like bridges. Although it was written for the RMNs, much of the information and detail (e.g., data forms) can be used by entities that are developing their own Quality Assurance Project Plans (QAPPs) and standard operating procedures documents (SOPs) for measuring stream temperature and flow.

This document differs from existing SOPs in that both temperature and flow information are compiled into one place, and deployment techniques specifically address challenges posed by year-round deployment. Efforts were made to include only methods that are formally published and/or have been shown to be effective in field tests. Because limited resources are available for implementation of the RMNs, whenever possible, protocols describe simple methods and reference inexpensive tools needed to collect data. If resources permit, there are many possibilities for collection of additional data at RMN sites. For example, if multiple temperature sensors are available for deployment at a site, they could be placed in different riffles to provide a measure of within-reach temperature variability. Or, for quality assurance checks, duplicate sensors could be placed at 10% of the sites, and/or a new sensor that will be replacing an older sensor could be deployed early so that there is overlap between deployment periods. While not covered in this document, the collection of these additional types of data would be very informative.

We attempted to make this document as comprehensive as possible, but acknowledge that there will be situations in which an alternative methodology, procedure, or process is warranted. Future updates and improvements will be made to this document 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 a minimum, at least one water temperature sensor should be deployed at each monitoring site. If resources permit, additional water temperature sensors may be useful at sites that have high reach-scale variability in temperature. Collection of air temperature data at individual sites is also useful, since air temperature is an important component of many modeling efforts (e.g., Hill et al. 2013) and can be used to determine if water temperature sensors are dewatered during their deployment (Bilhimer and Stohr 2009, Sowder and Steele 2012).

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

2.1. Equipment

In this section we discuss equipment that is needed for collecting air and water temperature data, as well as considerations that go into selecting the equipment.

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

Factors such as durability, accuracy, resolution, measurement range, memory, and battery life should be considered when selecting temperature sensors. For the RMNs, water temperature sensors should be durable (able to withstand years of use in challenging conditions), waterproof (i.e., IP code level 8), and have a minimum accuracy of ± 0.5°C (Table 1). In addition, proper calibration and accuracy checks (Sections 2.2.1 and 2.6.1) should be performed to ensure that sensors meet the specifications quoted by the manufacturers. If these steps are taken, the replacement of sensors every few years should not result in systematic bias, and any errors associated with equipment differences will be extremely small compared to the temperature variability within and among sites.

Air temperature sensors should have a minimum accuracy of ± 0.5°C as well. Water temperature sensors with accuracies of ± 0.2°C are currently available and should be used if possible at RMN sites (Table 2). Both water and air temperature sensors should have a measurement range that captures the full range of expected temperatures, a memory that is sufficient to record measurements at 30-minute intervals during the deployment period, and adequate battery life.

The lifespan of the sensor is another consideration. Some sensors are made to last 5 years or longer before their batteries run out and/or their cases start to leak. If sensors with non-replaceable batteries are used, be sure to document the sensor's use so you know when to take them out of circulation and budget/plan for their replacement. Regardless of what model is used, steps should be taken to minimize the number of different sensors deployed at the same site over time, so that inter-instrument error can be minimized. In addition, proper calibration and accuracy checks (Sections 2.2.1 and 2.6.1) should be performed to ensure that sensors meet the specifications quoted by the manufacturers. If these steps are taken, the replacement of sensors every few years should not result in systematic bias, and any errors associated with equipment differences will be extremely small compared to the temperature variability within and among sites.

Definitions of accuracy, precision and bias

Accuracy refers to how close the temperature measurement is to its "true" value. Precision is the variance or "tightness" of the temperature measurements. Bias refers to whether there is a systematic offset between the measured value and the "true" value.

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	± 0.5°C
Resolution[3]	< 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 may be necessary (a typically available range)

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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; expected to commonly experience
[3]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 has the capacity to 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, then it is not necessary to deploy a separate temperature sensor. However, even with an accurate temperature sensor in a transducer, a separate temperature sensor can be deployed as a back-up.

The same sensors that are used for measuring water temperature can be used to measure air temperature as long as 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 may be necessary). Less expensive, non-waterproof sensors can also be used to measure air temperature, as long as 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 currently commercially available temperature sensors can be 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, as long as the proper calibration and accuracy checks are performed to ensure that sensors meet the specifications quoted by the manufacturers (see Sections 3.2.1 and 3.7.1). Any errors associated with equipment differences are extremely small compared to the temperature variability within and among sites.

Table 2. Examples of commercially available temperature sensors

Manufacturer (web site)	Sensor model	Water-proof	Temperature range	Accuracy[1]	Resolution[1]	Battery life (typical use) & 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)	Thermochron ibutton (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 may be found on the manufacturer specification sheets
[2]As of January 2013 and subject to change; reduced prices may be available for bulk orders

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). In order to view the data, the appropriate software needs to be installed on the computer.

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. For the RMNs, instream data offloads are generally not possible because sensors should be 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.

Should I purchase a waterproof data offload device?

For added expense, one can purchase a waterproof data offload device (sometimes called a shuttle). It can be used to download data while the sensor remains in the water. However, at RMN sites, the sensors will be housed in protective shields, so the sensors will need to be removed from the cases (and the stream) prior to data download. In these situations, the main benefits of the waterproof shuttles versus the non-waterproof devices (often called base stations) 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.

Compatibility is important to consider when purchasing equipment. Ensure that the data offload device and software are compatible with the model of the temperature sensor. If purchasing multiple sensors, it is often most cost-effective to buy the same model since reduced prices may 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).

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 that are 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.

2.1.4. Considerations when choosing radiation shields

Temperature sensors must be outfitted with radiation shields because sunlight striking the sensors biases temperature readings (Figure 3) (Isaak and Horan 2011, Dunham 2005). These shields can also serve as protective housings and can 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.

> **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 may also increase vandalism rates, especially in heavily trafficked areas. If vandalism is a concern, use radiation shields that are neutral colors or paint them to reduce their visibility.

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 2 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 that epoxy can be wrapped around as the epoxy will not hold the PVC to the rock without this. More details on how to construct PVC canister shields, including specific part numbers, can be found in Isaak et al. (2013). An alternate method for constructing PVC canisters is described in Appendix A (Mauger 2008).

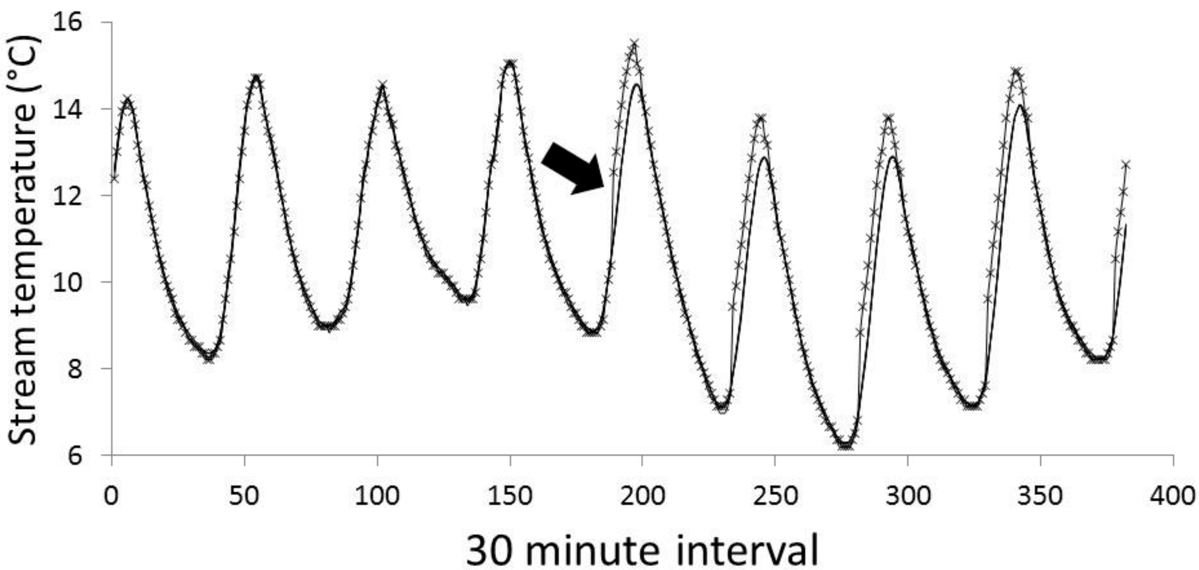


Figure 3. Stream temperature measurements from four sensors at the same site during eight days in July 2010. All sensors had solar shields during the first four days when temperature measurements overlap. The solar shield was removed from one sensor on day 5 (black arrow) and temperature spikes became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

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

PVC canisters should not be used as solar shields for air temperature sensors because they lack sufficient air flow. 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). It 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, since radiation reflecting off the snow can directly strike sensors and bias temperature readings (Holden et al. in review).

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 (Holden 2012, unpublished; Appendix B; Figure 5B) costs approximately $2.50-3.00 per shield. A comparison of the performance of this custom shield to commercially-available shields is described in 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.

A) B)

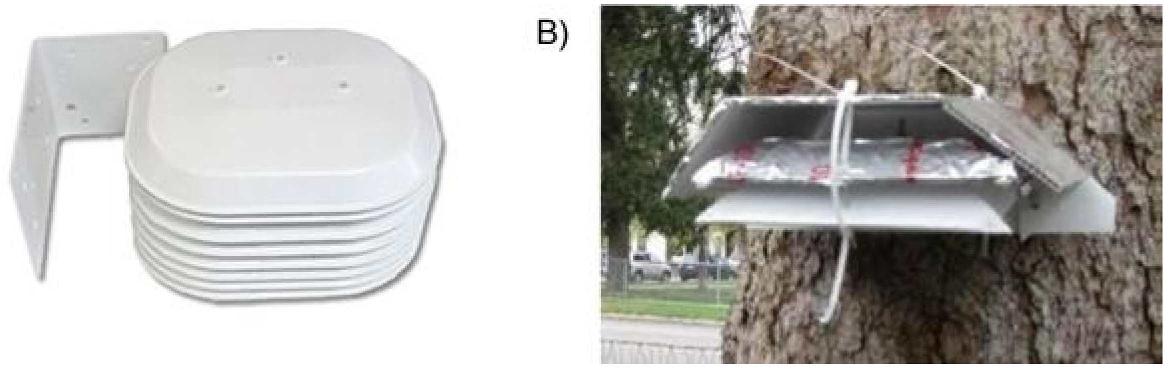


Figure 5. Examples of radiation shields for air temperature sensors include A) the Gill-style Onset RS1 solar radiation shield (www.onsetcomp.com) and B) custom design by Zachary Holden (Appendix B).

2.2. Pre-Deployment

2.2.1. Calibration/accuracy check

Before field deployment, a calibration procedure should be performed in-house to check the accuracy of the temperature sensors and to ensure that the sensors are launching and downloading data properly.

Table 3 presents a step-by-step procedure for doing a multiple-point temperature calibration. First, sensors should be set up to record at the same sampling intervals that will be used in the field (in this case, every 30 minutes). Next, the sensors should be exposed to alternating warm and cold cycles that approximate the temperatures and duration of diurnal fluxes that the sensors will be exposed to in the field. At various points during this process, temperature measurements should be taken with a National Institute of Standards & Technology (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, per 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.

All calibration data should be recorded on a calibration datasheet, similar to the one shown in Appendix C. These records and the digital data from the calibration test should be retained in a safe place for future reference since they can be used to assess drift rates if sensors are deployed for multiple years. Equipment needs for this procedure are listed in Table 4.

Table 3. Pre-deployment calibration procedure

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 get 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 thermometer; record the value on a calibration datasheet (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 calibration 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 (this should be $<$ 0.5 C for the water temperature sensors and ± 0.5 C for the air temperature sensors). Sensors that have anomalous readings should be set aside and returned to the manufacturer for replacement. 13. Record all of the calibration information on a calibration data sheet (like the one shown in Appendix C).

Table 4. Equipment needs for the pre-deployment accuracy check

Task	Supplies 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 (i.e. red liquid) thermometers (optional) • Containers to hold the sensors • Water • Refrigerator • Clock or watch
Recording measurements	• Calibration data sheet (Appendix C) • Computer that has the appropriate software for reading the temperature sensor

2.2.2. Sensor configuration and launch

When configuring the sensors, it is helpful to set them to local standard time, as this will simplify data processing (Ward 2011). Sensors can be programmed to start before or after the planned deployment time, or can be launched on-site. Whatever the timing, it is critical that field personnel record the exact time the sensor is correctly positioned in the stream channel so that observations recorded before and after that time can later be removed during data processing (Section 2.6.2).

For the RMNs, the sensors should be configured to record point temperature measurements in degrees Celsius at intervals of 30 minutes on the hour and half hour (e.g., 5:00, 5:30, 6:00, 6:30). If monitoring agencies are not able to visit a site annually and the sensor has insufficient memory capacity to record at 30-minute intervals for the deployment period, sensors should be programmed to record point measurements every 60 or 90 minutes. Figure 6 suggests that 60 minute intervals are likely sufficient, though 30 minute intervals may more closely match other continuous data collection efforts such as water levels.

The configuration and launch information for each sensor should be recorded on a datasheet, similar to the one shown in Appendix D. It should include serial number, programmed deployment time, and recording interval. For the RMNs, if the sensor has “sensor high, low and multiple sampling” features and “wrap-around-when-full, overwrite oldest data” functions, these should be turned off.

Considerations when choosing a sampling interval

Choosing a sampling interval is a balancing act. If long intervals are used, you may miss the maximum and minimum daily temperature since these may only be observed for a short time within a day. This would result in underestimating the warmest temperatures and overestimating the coldest temperatures. If too short an interval is used, it could use up too much memory, and requires 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, there is not much bias. Sites with larger diel fluctuations have a greater probability of missing the true maximum than those with smaller diel fluctuations.

For the RMNs, the 30-minute interval should be re-evaluated after the first year to determine whether a longer interval (i.e. 60 or 90 minutes) can adequately capture the thermal regimes at sites.

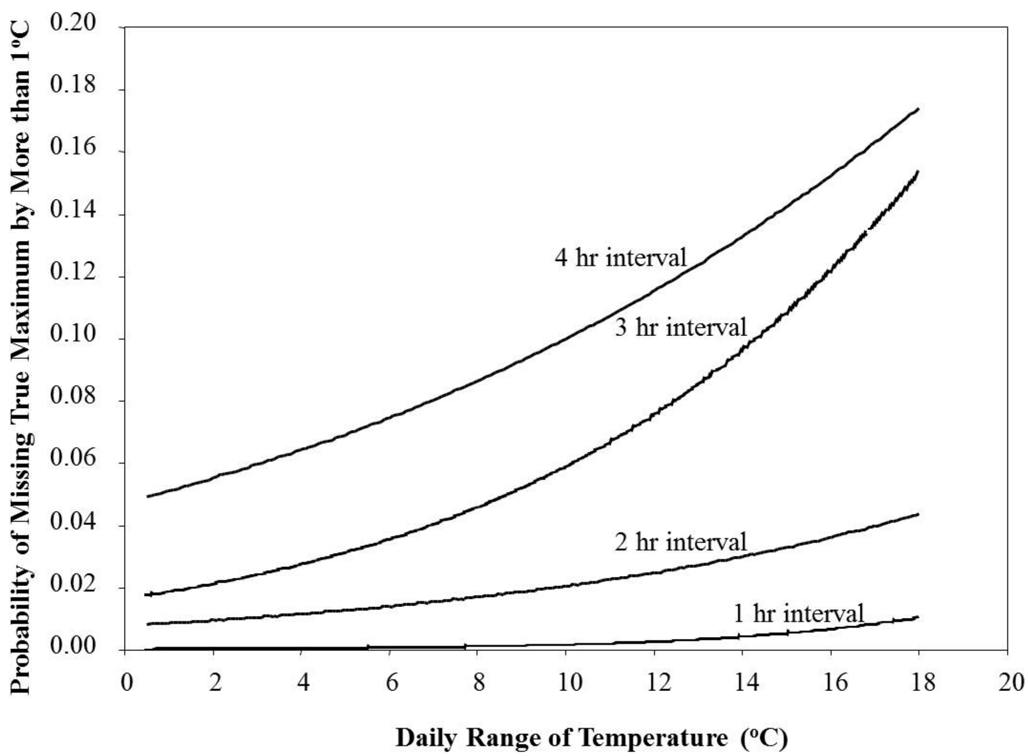


Figure 6. Probability of underestimating the maximum daily temperature at least 1°C in relation to daily range of temperature and sampling interval (Dunham et al. 2005).

2.3. Deployment of Water Temperature Sensors

At a minimum, one water temperature sensor should be deployed at each site. When deploying sensors, safety should always be a consideration, and sensors should only be placed in streams that can be safely accessed and waded by crew members. If possible, avoid reaches with very high gradients (>7%) since sensor retention rates are inversely related with slope (Isaak et al. 2013). Prior to installing the sensors, be sure to obtain permissions from all relevant parties (e.g., property owners if accessing sites will involve crossing private property, the local Department of Public Works if the water temperature sensor will be attached to a bridge abutment). Efforts should be made 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 man-made structures like bridges. If a situation occurs in which a sensor is attached to a bridge or other man-made structure, the biological sample should be collected at least 200 meters from the area of human disturbance. As long as the sensor is collecting data that are representative of the characteristics of the reach from which the biological data are being collected, the sensor does not have to be sited in the exact location that biota are being collected from.

2.3.1. Guidelines for placement within the stream

There is not a simple straightforward formula for selecting a location since each site is different, but in general, areas of well-mixed water moving through runs and pools are preferable over riffles. In addition, sensors should be deployed 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 was collected (e.g., not below additional warm or cold water sources). Note that for general monitoring purposes the sensor does not have to be placed in the exact location that biota are being collected from.
- Well-mixed horizontally and vertically
- Of sufficient depth to keep the sensor submerged year-round
- Stable and easy to re-locate
- Protected from physical impacts associated with high flow events (i.e. 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, anything that is moving is going to be well-mixed. To verify this, take numerous instantaneous temperature measurements in the vicinity of the deployment location. If the stream can be easily waded, then 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, since variability in these measures could indicate sources of thermal variation (Dunham 2005). If there is a high degree of variability in these measures, 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 may 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
    - stream side wetland areas
    - hotsprings
    - groundwater seeps

When possible, sensors should be deployed 6 inches (<0.5 ft) above the stream bottom (per Schuett-Hames et al. 1999). There may be situations (e.g., small, shallow streams) where you have no choice but to place a sensor near the stream bottom to ensure that it remains submerged during low flows. Note on the field form when situations like this arise, because influences from groundwater, subsurface flow, and the substrate can cause subsurface temperatures to deviate from temperatures in the well-mixed portion of the stream (Zimmerman and Finn 2012). Sensors should never be intentionally buried.

Also, when possible, sensors should be installed on the downstream side of the structure to which the sensor is being attached (e.g., a large rock or log), since high water velocities and associated substrate movement and transport of debris 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, since this will allow 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.

Site-specific conditions will dictate which installation technique is most appropriate. Below, we briefly describe two methods – the underwater epoxy method (Isaak and Horan 2011, Isaak et al. 2013) and a method in which cabling is used to attach the sensor to rebar or stable instream structures such as large rocks or boulders, woody debris, or roots (Ward 2011, Mauger 2008). Equipment needs for both installation techniques are listed in Appendix E.

If site conditions permit, the preferred method for year-round deployments is the underwater epoxy method, since it requires minimal effort and materials and provides durable installations that withstand floods and associated bed-load movement. Moreover, 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 (based on field trials, 80% - 90% of sensors installed correctly remained in place after 1- and 2-year intervals (Isaak et al. 2013).

2.3.2.1. Underwater epoxy

The underwater epoxy method can be used in multiple environments as long as there is a suitable anchor point, such as a large rock or cement structure (e.g., bridge support). Table 5 describes the step-by-step procedure for doing 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 surely dislodge it, not to mention the safety risk associated with lifting large boulders). Ideally, on the downstream side of the attachment point, there should be pockets of relatively calm water with smaller substrate sizes (if large rocks and cobbles are on the downstream side, it is likely that similarly large substrates will move there again during the next flood, and these could dislodge or break the sensor). Cement bridge pilings at road crossing are also good attachment points for this protocol. Photos of good attachment points are shown in Figure 7.

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). Selection of 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 and worked well in field conditions. The epoxy works well during installations in water temperatures ranging from 2 to 20˚C, but becomes less cohesive as temperatures warm. If applying this type of epoxy in water temperatures significantly exceeding 20˚C, run tests to ensure the epoxy sets within 24 hours of installation. Alternatively, installations with FX-764 could be done during times of the day when water temperatures are relatively cool to allow the epoxy to set. If a sensor needs to be reattached to a structure that has old Fox bonding agent on it, it is best to use a different attachment point if possible.

Crews that are inexperienced with this technique should first do some practice runs in the laboratory, and then do initial field installations at a few easily accessible locations that can be checked after a few days.

To monument a site, the epoxy can also be used to attach a metal forestry tag near the sensor location, which can make the sensor easier to relocate during subsequent site visits (Figure 7). 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).

Equipment needs for doing underwater epoxy installations are summarized in Table 6 and Figure 9. Additional details on doing underwater epoxy installations are available in Isaak et al. (2013) and in the YouTube training video (accessed 15 June 2013):

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

Table 5. Quick guide for doing underwater expoxy 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 • 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 (at least 2-3 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.

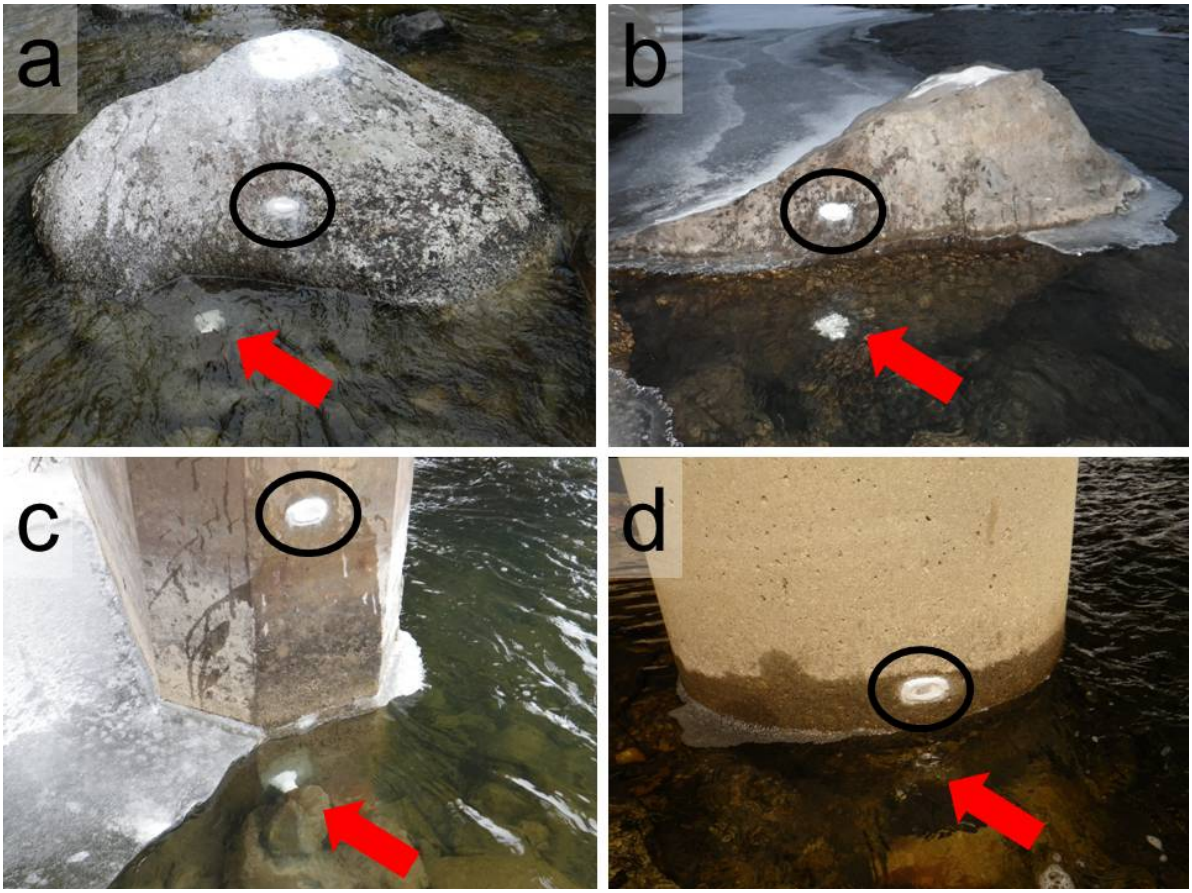


Figure 7. Examples of large rocks (a and b) and cement bridge pilings (c and d) that provide good sensor attachment sites. Each site has a flat downstream attachment surface that is shielded during floods from bedload and debris. Arrows point to the solar shield containing a sensor; circles highlight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

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.

Table 6. Equipment list for doing underwater epoxy installations (Isaak et al. 2013). Monumenting is discussed in Section 2.3.3

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

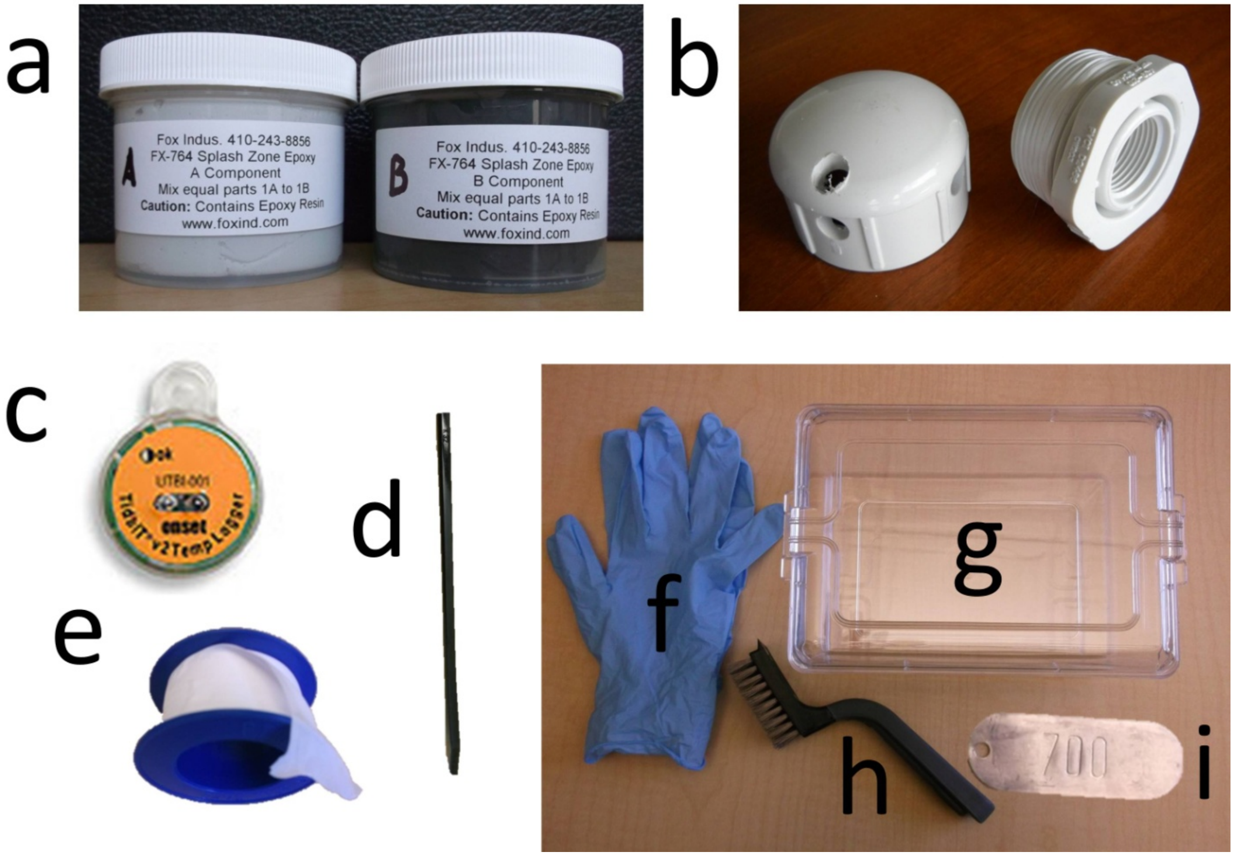


Figure 9. Equipment needed to permanently install temperature sensors in streams using underwater epoxy includes: (a) two-part FX-764 epoxy from Fox Industries, (b) PVC solar shield, (c) temperature sensor, (d) cable ties, (e) plumber's tape, (f) rubber gloves, and (g) plastic viewing box, (h) wire brush,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

2.3.2.2. Cabling the sensor to rebar or stable instream structures

If the underwater epoxy method cannot be used at a site, sensors may be cabled to rebar or stable instream structures like large rocks or boulders, roots, or woody debris. These techniques are commonly used and have been shown to be effective for seasonal summer deployments (Email, Bill Ward to Jen Stamp, January 4, 2013). A downside is that if these techniques are used for year-round deployments in streams that experience annual high flow events, sensors may sometimes be buried or dislodged by moving substrates.

Ideally the sensors can be attached to the downstream side of the instream structure, as this will shield the sensor from moving rocks or debris during floods. Cable ties and/or wire are used to attach the sensors to the structures. If you think the structure might move during high flow events, consider cabling or chaining the structure to something on the nearest bank (or to another stable instream structure).

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 (i.e. no near-surface bedrock or consolidated sediments), the rebar method is commonly used. A 2-3 foot length of rebar 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 cable ties or wire. Photos of a rebar installation are shown in Figure 10. More detailed descriptions of these methods can be found in Ward 2011, Mauger 2008, and Appendix F. An alternate technique that utilizes a low profile concrete base is also described in Appendix F.

Figure 10. Photos of a rebar installation (from Mauger 2008).

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 2005). Thus, it is critical that each sensor be accurately georeferenced and that sensor placement is documented in a way that allows field personnel to re-locate the sensor during subsequent visits.

Table 7 contains a list of guidelines for documenting sensor locations. First, GPS coordinates (latitude and longitude) should be recorded for the exact site at which each sensor is deployed, as well as the datum of the GPS. If unable to obtain GPS coordinates in the field, note the sensor location on an accurate map and determine the coordinates later. While GPS coordinates are useful for getting close to the site, they are insufficient by themselves, 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.

Photos should be taken from different perspectives (i.e., upstream and downstream), and should 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 may be appropriate. Detailed hand-drawn maps like the one shown in Figure 11 (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 12).

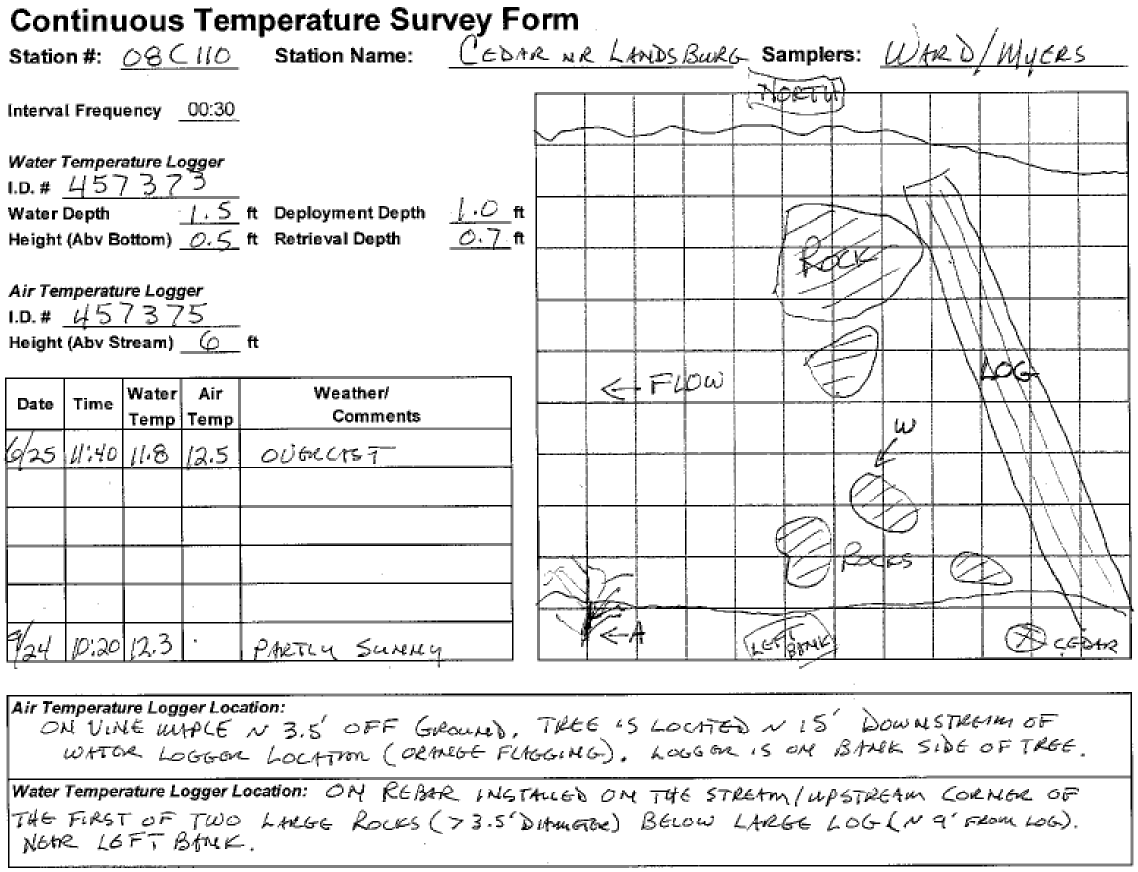
All documentation information must be recorded on a field form, like the form shown in Appendix D. Field forms should include information on station number, waterbody name, date, time, crew members, driving directions, serial number of sensor/s, time of deployment, sensor installation technique, image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

If the stream can be easily waded, an instantaneous stream temperature measurement 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. If time permits, the following additional measurements should be taken: the total stream depth at the sensor, the distance from the stream bottom up to the sensor, distance from water surface to the sensor and wetted width along a transect that intersects the sensor. In addition, it is helpful to do a cross sectional survey of the stream temperature, as described in the text box in Section 2.3.1, since these results will help verify that the stream temperature sensor is measuring representative temperatures and will also expose any cross-sectional temperature differences. Equipment needs for taking these measurements and for documenting sensors are summarized in Table 8.

Table 7. 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 whatever else may be appropriate and/or annotate photographs when viewing them later on a computer. • Complete field form.

Temperature and depth measurements	• Measure the following and record on field form:
	  ◦ Total stream depth at the sensor.
	  ◦ Distance from the stream bottom up to the sensor.
	  ◦ Distance from water surface to the sensor.
	  ◦ Instantaneous stream temperature at the location of the sensor, taken 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*.
	  ◦ Wetted width along a transect that intersects the sensor
	  ◦ If the stream can be easily waded, do a cross sectional survey of the stream temperature, as described in Section 2.3.1.



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

Figure 12. 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).

Table 8. Equipment list for documenting sites.

Task	Supply list
Georeferencing & monumenting	• GPS • Camera • Map and/or gazetteer • Metal forestry tags • Field form (similar to Appendix F, Figure 3.3-4)
Measuring temperature and depth	• NIST-calibrated field thermometer and/or multi-probe meter • Meter ruler or calibrated rod/pole (i.e. surveyor's rod) • Measuring tape

2.3.4. Common problems

As summarized in Dunham 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 9. 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.

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 won't 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, it will not be impacted by chunks of ice moving downstream.

Table 9. 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 and/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 it may also make the data sensor more difficult to relocate) • Secure the sensor in a 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

If possible, air temperature should be collected at RMN sites. The air temperature sensor should be located in the riparian zone, as close as possible to the water temperature sensor. Ideally, it should be installed in a place that is out of direct sunlight and has low potential for vandalism. As discussed in Section 2.1.4, temperature sensors must be outfitted with radiation shields so that sunlight does not strike the sensor and bias the temperature readings (Isaak and Horan 2011, Dunham 2005). Vegetation alone should not be used as the primary radiation shield.

Trees (ideally > 12 inch diameter) are the best attachment points for air temperature sensors because they provide stability and some degree of shade. If a suitable tree is present, attach the radiation shield and sensor to the north side of the tree using the simple four-step process described in Appendix B (Holden 2012, unpublished). 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 (Holden 2010, unpublished), 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 sensor to a 10-foot piece of ½ inch diameter PVC pipe, which can be purchased at a local building supply store. Using a drill, create a 1/8th 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 3-4 foot piece of metal rebar into the ground to a depth of approximately 1-foot, and slide the PVC pipe onto the rebar. *Please note that this method has only been used experimentally and has not been extensively tested.*

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, daily air temperature observations from the nearest active weather station should be compiled. 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).

There is value in obtaining data from the nearest weather station even if an air temperature sensor is installed at a site. For one, it could be used for quality assurance purposes (e.g., if a comparison of the two datasets reveals differences in patterns, it may be an indication that the on-site sensor is malfunctioning). Or, if the comparison shows there to be little difference between data sets, the weather station data could potentially 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. In the future, instead of weather station data, it may be possible to use modeled data. Higher spatial resolution, gridded air temperature models are currently being developed that account for terrain influences on temperature. These data will likely prove useful for understanding spatio-temporal variation in air temperature and its influence on streams.

2.5. Maintenance/Mid-Deployment Checks and Data Offload

When a site is first established, it should be revisited 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, sites should be visited annually to check the condition of the sensors, gather data for mid-deployment accuracy checks (Section 2.7.1), and offload data. This can be done in conjunction with the annual biological sampling events. If annual site visits are not possible, visit the site as frequently as your schedule permits, ideally during low flow conditions.

Table 10 and the field form in Appendix G contain checklists for performing these maintenance/mid-deployment checks and data downloads. For maintenance, look for signs of physical damage, vandalism, or disturbance. Also ensure that the sensor is not buried by sediment and remove anything that could bias the temperature readings (e.g., debris, aquatic vegetation, algae). Photographs should also be taken to document any changes to the monitoring location during the course of the study.

To gather data for the mid-deployment accuracy checks (Section 2.7.1), collect instantaneous stream temperature measurements near the sensor with a NIST-calibrated field thermometer, as close as possible to the time when the sensor is recording a measurement.

Procedures for data offload will vary depending on the model of the temperature sensor and the data offload device. Typically, start by attaching the temperature sensor to a base station or shuttle and then connect the data offload device to a computer that has the appropriate software (Figure 2). 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 may affect its ability to connect. Be careful not to scratch the sensor optic communication area when doing this. Once the connection is established, follow the manufacturer’s downloading procedures. The data transfer should be done in a way that minimizes the disruptions/discontinuities in the long-term temperature record.

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 there are unusual readings, 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 need to be replaced each year, while others, like the Onset TidbiT v2, last five years or longer under normal use); and
- back up the data (e.g., onto a flash drive) before clearing the sensor memory.

If it is impractical to bring a laptop into the field, 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, redeploy the same sensor at the site, as this will minimize inter-instrument error. If the sensor needs to be removed from the site (e.g., due to low battery life), before leaving the site, mark the sensor with a temporary tag identifying the site, date, and time of retrieval, and replace it with another calibrated sensor. It is very important to accurately record the time and date of retrieval, 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.

If conditions permit, the stream temperature and depth measurements described in Table 7 should be collected during each site visit, as should an instantaneous air temperature measurement. The instantaneous stream and air temperature measurements should be taken with a NIST-calibrated thermometer at the sensor locations, as close as possible to the time of the expected sensor recording. These measurements and information on sensor condition should be recorded on a field form like the one shown in Appendix G. Equipment needs for taking these measurements and for conducting maintenance/mid-deployment checks and data downloads are listed in Table 11.

Table 10. 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 isn't, move it to a location where it is covered by water and will remain so during periods of base-flow. • Make sure the sensor is not buried in sediment. If it is, remove the sediment and reinstall the sensor in a location 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 towards cooler temperatures by hyporheic flows. In many cases, temperature recordings from buried sensors should be destroyed due to the large amount of bias incurred and because adjustments are difficult to apply with accuracy. • 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 may impact 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 field form (like the one shown in Appendix F).
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 may 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 the manufacturer's downloading procedures. • Clear the sensor memory as necessary to ensure sufficient capacity for continued deployment.

Sensor retrieval	• If a sensor must be removed from a site, before leaving the site, mark the sensor with a temporary tag identifying the site, date, and time of retrieval.

Temperature and depth measurements	• Measure the following and record on field form:
	  • Total stream depth at the sensor
	  • Distance from the stream bottom up to the sensor
	  • Distance from water surface to the sensor
	  • Wetted width along a transect that intersects the sensor
	  • If the stream can be easily waded, do a cross sectional survey of the stream temperature, as described in Section 2.3.1.

Table 11. Equipment list for conducting maintenance/mid-deployment checks and data downloads

Task	Supply list
Relocating sensor	• GPS • Map and/or gazetteer • Annotated photos and/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) & data back-up device (e.g. flash drive)
Measuring temperature and depth	• NIST-calibrated field thermometer and/or multi-probe meter • Meter ruler or calibrated rod/pole (i.e. surveyor's rod) • Measuring tape
Back-up equipment (in case a sensor needs to be replaced)	• Calibrated replacement sensors and other necessary deployment equipment

2.6. Quality Assurance and Control

Quality assurance and control procedures must be performed after data are offloaded and/or sensors are retrieved to verify the quality of the data and to check for potential errors. Records of these procedures must be documented on a form like the one shown in Appendix H and stored for long-term record keeping (ideally in a central database that someone maintains).

The series of data cleaning steps described below can improve data quality, reduce the time and effort of data processing, and increase collaboration and comparison across projects, streams, and regions (Sowder and Steele 2012).

2.6.1. Mid- and post-deployment accuracy checks

Some sensors will be deployed for multiple years (e.g., Onset TidbiT v2 sensors last 5 years or longer under normal use). When possible, mid-deployment accuracy checks should be performed on these sensors by comparing downloaded sensor values to the values of the instantaneous stream temperature measurements that are collected with a NIST-calibrated field thermometer during mid-deployment checks (see Section 2.5). If sensors are retrieved (i.e., brought back to the office/laboratory), a post-deployment accuracy check should be performed, using the calibration procedure described in Section 2.2.1.

When sensor values are compared to the values from the NIST-certified thermometers, they should not exceed the accuracy quoted by the manufacturer (± 0.5 C). If a sensor fails this check, repeat the procedure. If it fails a second time, flag the data with an appropriate data qualifier.

2.6.2. Error screening

Sensors may record erroneous readings during deployment for a variety of reasons. For example, sensors may come out of the water as a result of low flow conditions, high flow events may bury sensors in silt, sensors may malfunction, or humans may cause interference. Therefore, a standard set of procedures should be performed to 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) are described in Table 12. The first step involves removing observations recorded before and after the sensor is correctly positioned in the stream channel. 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, perform the series of automated and visual checks described in Table 12. The automated checks will flag missing data and data points that fall outside expected thermal limits. The visual checks are important because they pick up different types of errors (e.g., a dewatering event in the spring when air temperatures do not exceed the thresholds of the automated checks), and can be used to specify the time and duration of errors in the raw data files.

Table 12. Error screening procedure (based on Sowder and Steel 2012 and Dunham et al. 2005)

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.
Automated checks	• Missing data • 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*.
Visual checks	• Plot individual data points to look for 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 • Graphically compare data across sites • Graphically compare data across years; when data from one year are dramatically different, there may be data errors • Graphically compare with flow data (if available)

If observations are flagged, attempts should be made to re-verify these data with personnel involved in sensor programming, deployment, and retrieval. Flagged values should not be removed from the data file unless obvious problems are found, since it is possible that an extreme or unexplainable event is accurate and important to study. If confirmed anomalies are deleted from the data file, document these changes (along with reasons for making these changes).

What if sensor drift has occurred?

If drift occurs, it often occurs in very small amounts (e.g., 0.1 C per year). Those data can be retained. In situations where there is a large amount of drift and there is no way to tell when and how much the sensor was ‘off’ by, the data should be removed. This is one of the reasons why the accuracy of the sensors should be checked at the end of the deployment period.

Various software applications can be used to help with the error screening checks, data management, and calculation of various summary statistics. The software that is purchased with the temperature sensor(s) is likely going to have some applications like this. Other options include the following free applications that can be downloaded from the U.S. Forest Service, Rocky Mountain Research Station stream temperature website (http://www.fs.fed.us/rm/boise/AWAE/projects/stream_temperature.shtml):

- Thermo Stat 3 software package (Jones and Schmidt 2012)
- A SAS temperature data processing macro

A macro for R software is not yet available.

In addition, the Washington State Department of Ecology has developed the FMU Access® Data Logger Database, which is available upon request (Ward 2011).

2.6.3. Record keeping

Even if the set of standardized procedures described in Section 2.7.2 are followed, the data cleaning process is inherently subjective, so both the original and the cleaned data files should be maintained and backed up. Large amounts of stream temperature data will accumulate quickly so a central temperature database should be developed and maintained from the initial stages of monitoring. Also, all calibration and field forms should be organized, easily accessible, and archived in a way that allows for safe, long-term storage.

3. STREAMFLOW

The protocols in this section discuss how to install and maintain equipment to measure streamflow in wadeable streams, by measuring continuous stage (depth) and converting it to discharge (streamflow). 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) (Division of Ecological Restoration 2010, Chase 2005), the United States Geological Survey (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. There are many different types of sensors that 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

There are two basic components that are required to measure stream stage over time:

- A submersible pressure transducer, which provides continuous monitoring and logging of water level. At RMN sites, transducers should be encased in housings to protect them from currents, debris, ice, and other stressors (Section 3.1.4).

- A staff gage, which is a graduated measuring tool from which stream stage (depth) can be read (see Section 3.1.3).

Pressure transducers record absolute pressure, which software then converts to water level. Because atmospheric pressure changes with weather and altitude, it is necessary to compensate for barometric variations; 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; and 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 can be a cable that comes with the transducer and connects directly from the data logger to a computer or it may be a data shuttle that is purchased separately. The data shuttle used for the Onset temperature sensors (as 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

The two main types of pressure transducers are:

- **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 is downloaded directly from the on-land logger).

Data downloads are quick and there is no risk of placing the transducer back at a different elevation.
    - Data is 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., animals did not chew cable). Extra precautions must be taken to ensure ice does not crimp vented cable in streams with ice cover.
    - The transducer can be subject to vandalism due to increased visibility of 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 may be easier to hide in the stream than a vented transducer.
    - There is no vented cable to maintain. These transducers may 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 software provided by the manufacturer. 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 in order to download data. Care must be taken to ensure that the transducer is placed back in the same location and elevation every time data is downloaded.

Transducers at RMN sites should meet the following specifications:

- **Transducer accuracy** - at least ±0.1%

- **Range of stream stages -** slightly larger than the maximum expected range in the stream. A site visit prior to purchasing the transducer will help determine the expected range of flows. Since accuracy decreases as range increases, chose the smallest possible range. A depth range of less than 15 feet should be suitable at most RMN sites.

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

Examples and pictures of some commercially available pressure transducers can be found in Table 13 and Figure 13. Research your options carefully, and be sure to account for the fact that non-vented transducers may require the purchase of a second transducer to measure barometric pressure on land. Battery type (replaceable vs. non-replaceable) and memory capacity should also be considered.

If you are using a non-vented transducer, it may be possible to use barometric pressure data from the nearest active weather station instead of deploying an on-land transducer. This should be evaluated on a site-by-site basis, by performing the following steps:

1) Locate the closest active weather station. This can be done using online resources like Utah State University's Climate Database Server (http://climate.usurf.usu.edu/mapGUI/mapGUI.php)

2) Determine whether barometric pressure data are available at the station. If so, research the following –

- How often are the data recorded? Does the time interval overlap with the in-stream transducer? If not, can they be adjusted to match?
- What types of quality assurance and control measures are performed on the weather station data?
- Who runs the weather station? Where does the funding come from (and is the funding situation stable)?
- Are there known issues (e.g., expected maintenance, upgrades) that will cause the station to go out of operation during the period of sensor deployment?

3) Evaluate how well the weather station data are likely to approximate on-site conditions by:

- Calculating the distance between the weather station and the site (the closer they are, the better).
- Comparing the elevations of the sites and examining topographical differences (is one site located in a valley and the other on a mountain?) (the less difference, the better).
- Examine differences in weather patterns (the sites should be subject to similar weather patterns).

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, and the weather station is expected to remain in operation during the period of deployment, the on-land transducer could be removed from the site and could potentially be deployed elsewhere. Whichever data source is used, it is critical that the barometric pressure readings accurately represent on-site conditions, since failure to account for pressure variations will result in erroneous water level measurements.

There is also value in obtaining precipitation data from the nearest weather station (if available), since precipitation and flow are often closely linked. As a quality assurance check, patterns in the precipitation data could be compared to patterns in the water level data. If the patterns differ, this could be an indication that the water level sensor is malfunctioning. In addition, a similar quality assurance check could be performed using flow data from the nearest USGS gage.

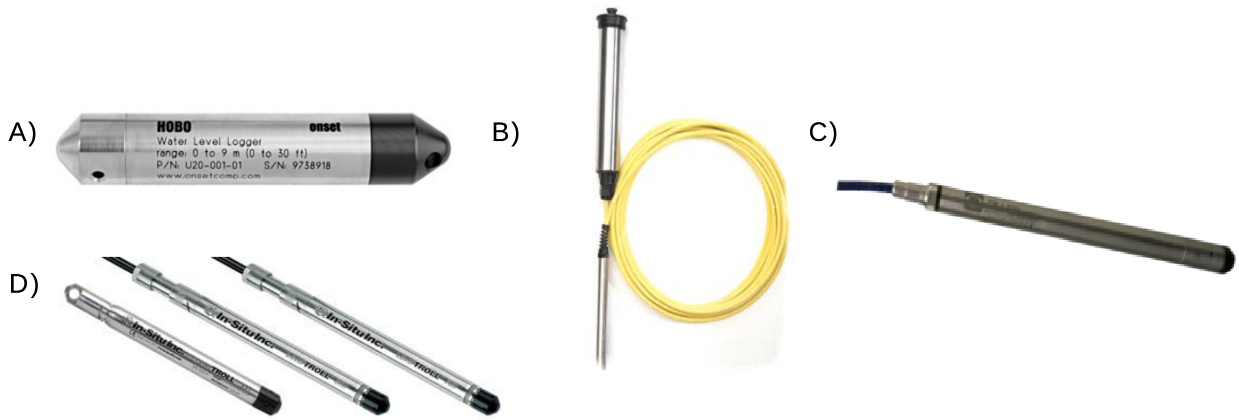


Figure 13. Numerous pressure transducers are commercially available. Some examples include: A) Onset Hobo© Water Level Data Logger; B) Global Waters Water level logger (WL16); C) INW Submersible Pressure & Temperature Smart Sensor (PT2X); D) In-Situ Level TROLL.

Table 13. Examples of commercially available pressure transducers

Manufacturer & Sensor Model	Type[1]	Operation range	Accuracy[2]	Battery life (typical use) & replaceability	Logger Memory	Approx. price[3] ($)	Web site
Onset Hobo© Water Level Data Logger (U20)	Non-vented	-20° to 50°C	±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[4] (64K bytes)	$495 (instream) + $495 (on land)	www.onsetcomp.com
Global Waters Water Level Logger (WL16)	Vented	-30° to 85°C	±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 (2 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	-15° to 55° C	± 0.05% Full Scale (typical), ± 0.1% Full scale (maximum)	18 months at 15-minute interval; user replaceable	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	Vented or Non-Vented	-20° to 80°C	±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 on what this means). 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] 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.
[3] As of January 2013 and subject to change; reduced prices may be available for bulk orders.
[4] Readings can be taken at 15-minute intervals for approximately 112 days before the memory capacity is reached.

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 provide a stable attachment point for the transducer. Gages at RMN sites should be USGS style (Style A) and marked every 0.02 feet (Figure 14).

Figure 14. Example of a USGS style staff gage (Type A) marked in 0.02 foot increments.

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. If vandalism is a concern, the housings can be painted black or camouflage to make them less visible. Inexpensive housings can be constructed from 1.25” or 1.5” diameter Schedule 40 (or stronger) PVC pipe. Multiple ½ inch or larger holes should be drilled into the PVC to allow water to fluctuate at the same rate as in the stream (Figure 15). In streams that are subject to extended ice cover, the entire length of the transducer as well as the vented cable may be encased in PVC to prevent potential damage.

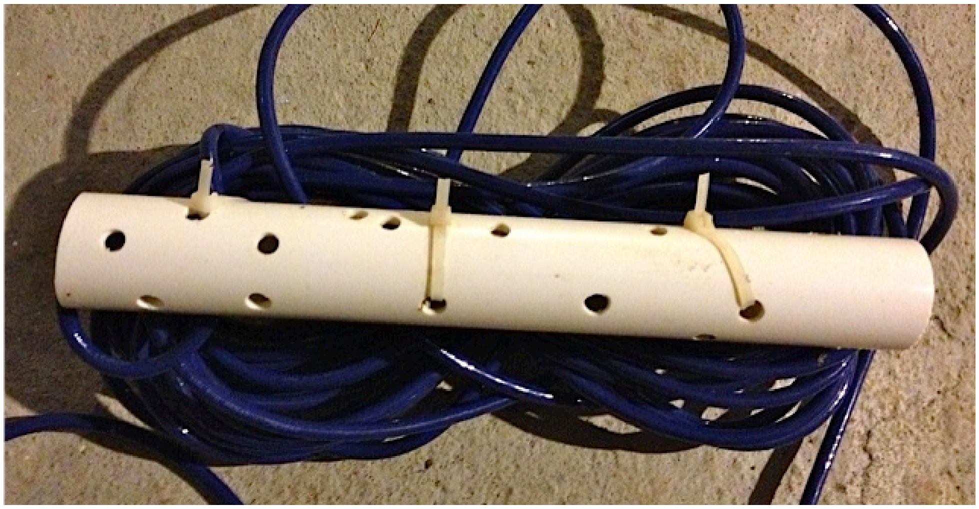


Figure 15. Example of a protective housing made of PVC pipe. This one is for a vented pressure transducer, which is secured inside the pipe with zip ties. If vandalism is a concern, the PVC can be painted to make it less visible.

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 re-deployment.

3.2.1. Calibration

Most transducers will be factory calibrated prior to being shipped. The calibration 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 16 illustrates how staff gage readings can be used to check the accuracy of the transducer data over time. The pressure transducer data is compared with the staff gage readings at similar times to determine the offset between the two. If transducer data does not correspond to staff gage data and water depth, there may be fouling of the transducer, it may need to be recalibrated, and/or it may 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 re-calibrate 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 may need to be returned for service.

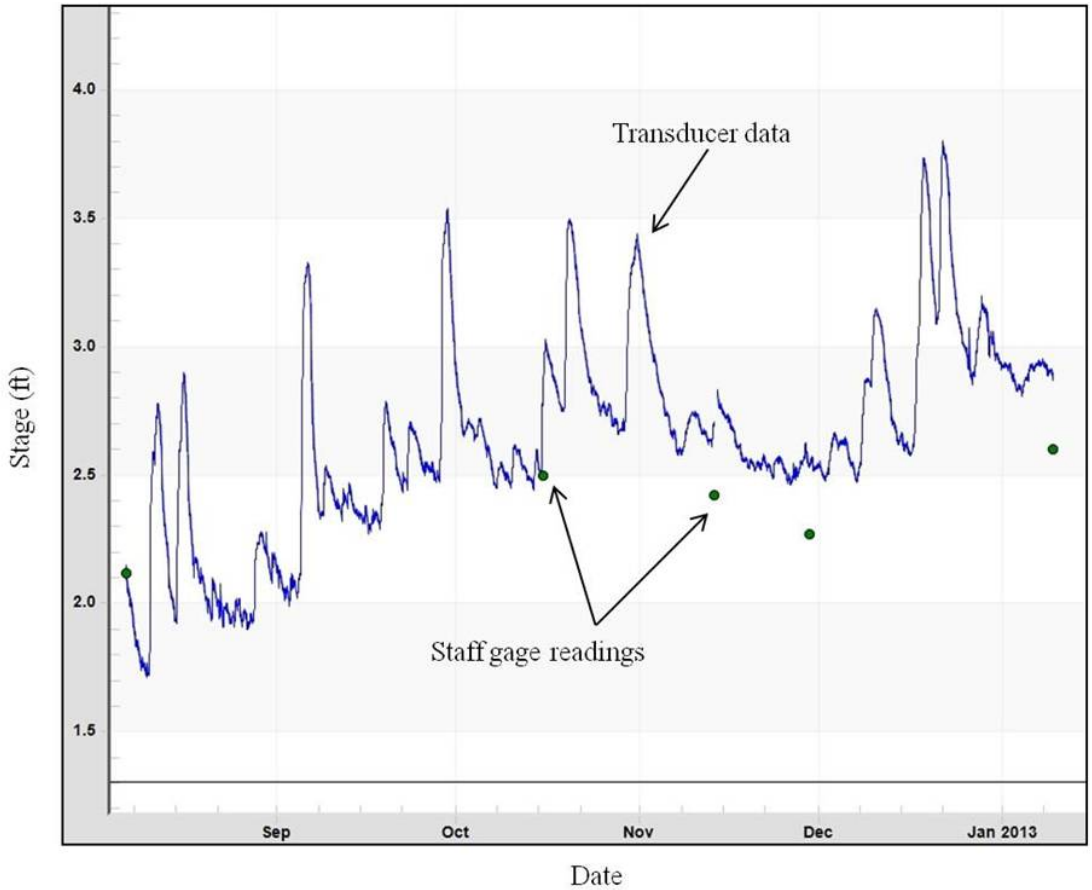


Figure 16. Staff gage readings provide a quality check of transducer data. In this example, staff gage readings stopped matching transducer readings in November, indicating that the transducer or gage may have changed elevation.

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 is 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.

It is helpful to bring a computer into the field to launch the transducer and check the logged data once it is installed. Alternatively the transducer may be launched prior to deployment as long as a note is made of the date and time of actual deployment in the stream (this is important for data screening – Section 3.7.2).

3.3. Deployment of Instream Pressure Transducers

Installation of both staff gages and pressure transducers are covered in this section since 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. Prior to installing the equipment, permissions from all relevant parties should be obtained. 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. Efforts should be made 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, it may be best to attach equipment to man-made structures like bridges. During the site visit, determine what type of installation is best so that appropriate equipment can be obtained prior to installation. If a situation occurs in which a transducer is attached to a bridge or other man-made structure, the biological sample should be collected at least 200 meters from the area of human disturbance. As long as 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 sited in the exact location that biota are being collected from.

Key considerations for siting in-stream transducers are listed below. These are similar to those used for water temperature sensors (see Section 2.3.1). More detailed information on site selection and controls may 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 was collected. Note that for general monitoring purposes the sensor does not have to be placed in the exact location that biota are being collected from.

- 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 17, Rantz et al. 1982). Natural controls may include a downstream riffle, bedrock outcrop, or other stream feature that controls flow. Unnatural controls may include a bridge or culvert that is narrower than the stream channel and constricts flow. Note that the feature controlling the stage-discharge relationship may change at different flow levels; such changes will be reflected in the rating curve.

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

Figure 17. 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 18). 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 potentially knock over the gage. A list of equipment needed for installation is in Table 14.

Gages are typically available in 3.33 foot sections; multiple gage sections may be combined to encompass the entire range of stages expected to occur in that section of the stream (additional sections may 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 19). Use concrete anchors on both sides of board and at varying elevations to ensure the stability of the board. Two anchors are typically sufficient for a three-foot gage and three for a six-foot gage.
- Use a hammer drill or rotary hammer with concrete drill bit to drill holes in the marked locations.
- Pound concrete wedge anchors (bolts) into holes using a hammer until they are secure.
- Drill holes in gage board for concrete wedge anchors.
- Place board over bolts and screw into place using nut.

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

- Use a pry bar to test the streambed in the pool for locations where the pole will be able to go into the bed.
- Drive a galvanized steel pipe with cap into the streambed using a pole (fencepost) driver or sledgehammer. Six foot and nine foot poles 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 may 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 flow and, if possible, positioned so that it may be read from the stream banks.

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

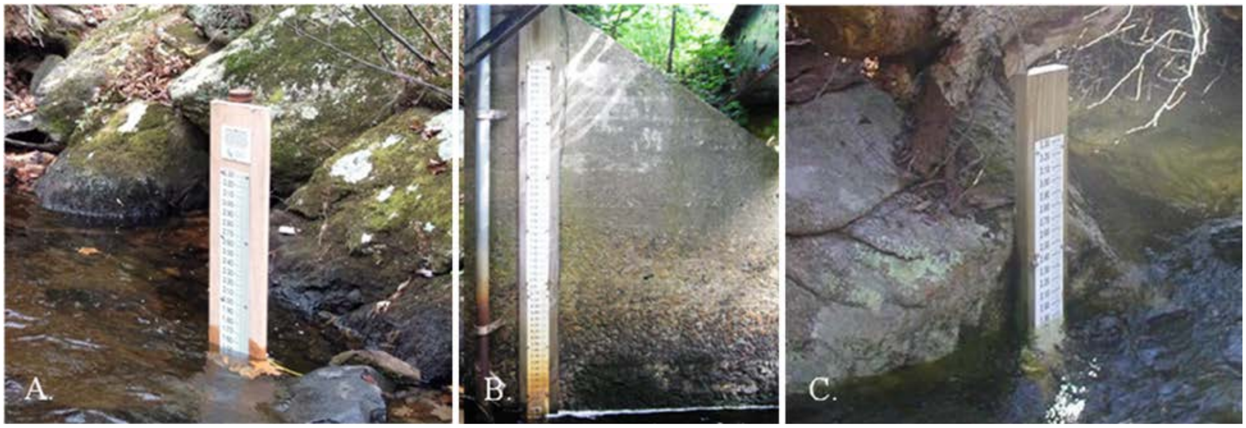


Figure 18. Examples of gage installation techniques include, A. streambed, B. fixed object (bridge wing wall) and C. fixed object (boulder).

Figure 19. Example of a 0.5 x 3.75 inch wedge anchor with bolt and washer.

Table 14. Equipment list for staff gage installation

Location	Supplies 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

3.3.3. Pressure transducer installations

Two types of installation techniques for pressure transducers are described in this document: 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. If site conditions permit, transducers at RMN sites should be installed using the fixed object method since it is more likely to withstand floods and associated bed load movement, and it is easier to ensure that the transducer remains in the same place over its period of deployment.

3.3.3.1. Fixed object

With the fixed object method, 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 PVC housing (Section 3.1.4). For vented transducers, which do not need to be removed from the stream to download data, the PVC pipe should be cut to a length at least slightly longer than the transducer. Use zip ties to attach the transducer to the PVC pipe to ensure it does not move (Figure 15). Do not leave slack in the zip ties. If the unit can move, it can wear through the zip tie.

Non-vented pressure transducers typically need to be removed from the stream to download data. To facilitate the removal and download of data during periods of high water, 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 20). 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 20). Clearly mark the holes for the bolt so that the transducer is placed back at the same elevation every time it is removed.

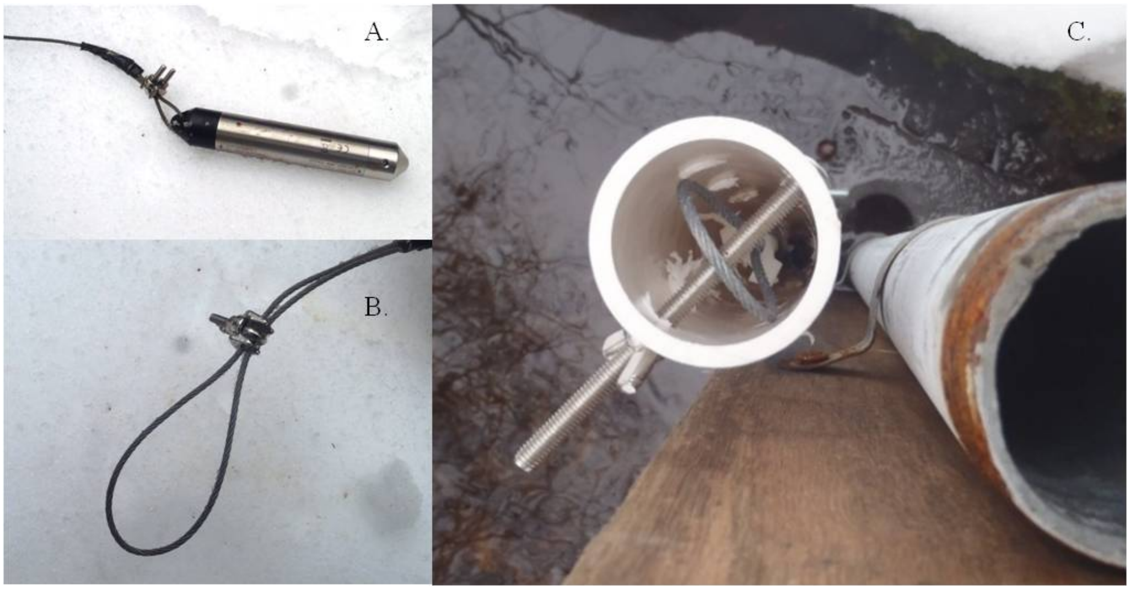


Figure 20. Non-vented pressure transducer installation. A. Non-stretch cable is attached to transducer, B. Loop is made at non-transducer end of cable, C. Cable with transducer is suspended over bolt from top of PVC pipe.

Once the pressure transducer has been installed in the protective housing, the transducer/housing can then be attached vertically to the staff gage board (Figure 21), a bridge abutment or fixed object, or horizontally to rebar or other pipe in the stream bed. An equipment list for performing installations can be found in Table 15.

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.

Figure 21. Non-vented (left) and vented (right) pressure transducers attached to staff gage board using conduit hangars.

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

- Install the transducer in close proximity to the staff gage so that stage changes are comparable.
- Use concrete anchors and conduit straps, hangar, 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.

Table 15. Equipment list for transducer installation

Location	Supplies list
All	· PVC pipe for transducer (drilled with ½" 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). *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

3.3.3.2. Streambed/rebar

If it is not possible to attach the transducer to a staff gage board or other fixed object in the stream (Section 3.3.3.1), a streambed installation may be possible (Figure 22). With this method, the transducer is laid horizontally on the streambed and is held in place by rebar and rocks.

Compared to the fixed object method, transducers are more prone to moving or being swept away during high flows, and it may be more difficult to ensure that transducers are returned to the exact same location after being removed for data downloads. However, this technique has been shown to be effective in short-term deployments (Roy et al. 2005).

Streambed installations require rebar stakes and a sledgehammer in addition to the equipment listed in Table 15. Installation instructions are as follows:

- Find a pool location in close proximity 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, and/or place large rocks over the PVC pipe.
- Ensure that the PVC pipe and transducer are installed slightly above the streambed to reduce chances of fouling by fine sediments.

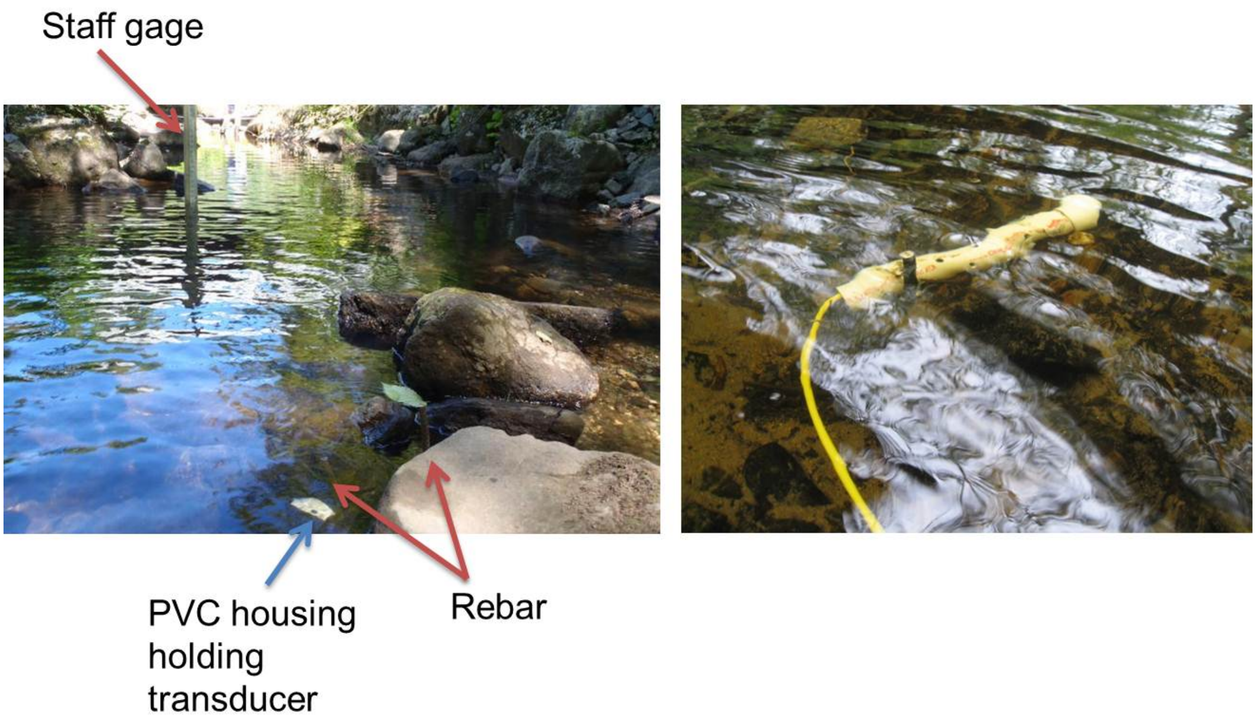


Figure 22. Examples of streambed installations of pressure transducers using rebar.

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 trees are absent, install a stainless steel pole (with a cap on it) and attach the data logger to this. Use the same type of pole that is used for the streambed staff gage installations. Do your best to 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 may be suspended on a wire or cable. If the data logger is not supported by the PVC pipe, it should be suspended on a wire or cable so there is no pressure 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 for downloading 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 23). Adjust the length of the pipe to adequately cover the device with some extra room.
- 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:

- 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 may be encased in a PVC pipe.

Specific considerations for the barometric pressure sensor:

- 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 24)).

Figure 23. Vented transducer data logger installation using A. stainless steel conduit straps and B. cable ties.

Figure 24. Barometric pressure sensor installation for a non-vented transducer A. without the PVC cap on top and B. with the PVC cap.

3.5. Elevation Surveys and Documentation

After the installation is complete, the pressure transducer location should be georeferenced and documented in a way that allows field personnel to re-locate the sensor during subsequent visits. Photos should be taken from different perspectives (e.g., upstream and downstream); these are important for relocating the instruments and documenting any changes to the monitoring location during the course of the study. All documentation information must be recorded on a field form that includes information such as station number, waterbody name, date, time, crew members, driving directions, serial number of sensor/s, time of deployment, transducer installation technique, image numbers/file names for the photographs, and detailed descriptions of transducer placement. It is very important to accurately record the time and date of deployment, as this information will be used in the error screening procedure described in Section 3.7.2.

In addition, the elevation of the staff gage and pressure transducer should be surveyed to establish a benchmark or 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. Elevation surveys should be conducted at least once a year to identify if and when movement occurs. It is particularly important to check for movement after high flow events and periods of extended ice cover. Steps for conducting elevation surveys using an auto level are summarized in Table 16, and Table 17 contains a list of equipment needs.

The elevation survey should be conducted on the day of staff gage and transducer installation. A benchmark and one to two other permanent markers should be identified or established 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. It is not necessary to know the absolute elevation of the benchmark as the purpose is to detect changes in elevation of the equipment relative to the benchmark. The benchmark may therefore 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 25); 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.

Once markers are established, sketch their location on the data sheet (see example in Figure 26), clearly documenting both markers and relevant site features that may 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 16). 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:

Height of instrument (H.I.) = Backsite (B.S.) + Elevation of benchmark (B.M.)

Elevation of survey point = H.I. – Foresite (F.S.),

where B.S. is the height of the stadia rod at the benchmark, 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 previous surveyed elevations to see if movement occurred.

Figure 25. Example of auto level and tripod used for elevation survey (A) and of a permanent structure used as a benchmark (B).

Table 16. 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. 2. Level auto level by centering the level bubble using the foot screws. 3. Have person hold stadia rod on top of benchmark. Rod must be level. 4. Read elevation at which crosshairs in auto level cross the stadia rod. 5. Record this elevation as the starting backsite (B.S.). 6. Have person hold stadia rod on survey point #1. Rod must be level. 7. Read elevation at which crosshairs in auto level cross the stadia rod. 8. Record this elevation as the foresite (F.S.). 9. Repeat steps 6 to 8 for additional survey points (including the top of the staff gage and transducer). 10. Have person hold stadia rod on top of benchmark. Rod must be level. 11. Read elevation at which crosshairs in auto level cross the stadia rod and record as final B.S. 12. If final B.S. does not match starting B.S. (within 0.01 ft), repeat the entire survey.

Table 17. Equipment list for elevation surveys

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

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:

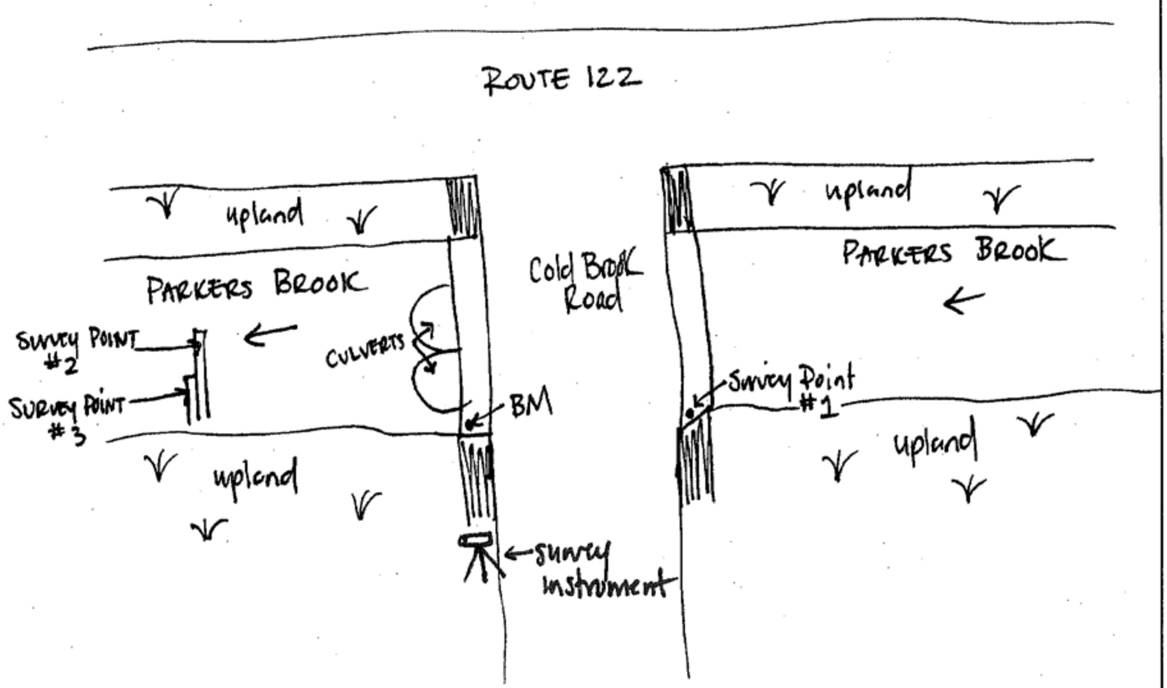


Figure 26. An example of a completed elevation survey form.

3.6. Maintenance/Mid-Deployment Checks and Data Offload

When a site is first established, it should be revisited within the first month to confirm that the installation is holding properly. After these initial deployment checks, at a minimum, sites should be visited at least annually (e.g., in conjunction with the biological sampling events), but more frequent visits are encouraged, 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 as well as data quality.

During site visits, field personnel should:

- Check the condition of the transducer and perform necessary maintenance.
- Take staff gage readings, ideally at different flow conditions, for quality assurance and control purposes.
- Offload data.

Typical maintenance issues include:

- Ensuring that the instream pressure transducer is *submerged and not buried in sediment.*
- *Clearing leaf litter and debris* that may pile up against the gage, transducer, and downstream control. At the beginning of a site visit, clear this material as it may 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 may change if there is sediment accumulation or scour 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 alternate 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 off 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) may 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, data should be downloaded 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 27). Prior to download, record the stage at the staff gage and note any factors which may 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, a form like the one shown in Figure 28 should be completed.

Battery life should also be checked. Batteries in some sensors need to be replaced each year, while others last 5 years or longer under normal use. Do your best to plan for these replacements, and try to minimize the number of different transducers that need to be deployed at a site through time so that inter-instrument error can be minimized.

Information from mid-deployment checks should be recorded in a field notebook or on a field form. Entries should include notes about the condition of the transducer, staff gage readings and whether any unusual measurements appeared during the data spot-check (if available). It is also important to take photos during each site visit, as this will help document changes to the monitoring location during the course of the study

Figure 27. 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 28. Example of a transducer download field data sheet.

3.7. Quality Assurance and Control

Proper quality assurance and control 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 may 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, it is important to make periodic staff gage readings to detect any shift or drift in the transducer data. The gage depth should be recorded every time the site is visited for a discharge measurement or data download. It is ideal for gage readings to be done at least every month, if possible, to assure 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 may assist with gage readings. Local watershed groups or other organizations may be able to help to identify local volunteers. At the minimum, try to visit sites after large storm events that may impact the transducer.

3.7.2. Error screening

Pressure transducers may record erroneous readings during deployment for a variety of reasons (e.g., they may become dewatered during low flow conditions, high flow events may bury them in sediment, humans may cause interference). The types of errors that can occur and how they manifest themselves will vary. For example, if moisture gets into the cable, it may result in erratic readings or readings of zero water depth. If the cable gets kinked or plugged, it can result in the data not being corrected for barometric pressure. Because these errors may occur, data need to be screened.

The first step involves removing observations recorded before and after the transducer is correctly positioned in the stream channel. 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 dewatered or buried in the sand) and flag those data accordingly.

Next, perform the series of checks described below:

- **Outliers.** Graphing data over time and against precipitation data from a nearby weather station provides a quick way to identify and flag obvious outliers (e.g., negative numbers during periods of normal streamflow, very high numbers when there was no precipitation or other known cause, data gaps). Evaluate and, if possible, correct the cause of data outliers.

- **Accuracy.** Compare staff gage readings to appropriate transducer measurements. If the difference between staff gage and transducer readings at a given time is more than 5%, additional analysis will be necessary to determine if a data shift or data drift occurred during the deployment period.
- **Data shift/drift.** Data drift is when the difference between the staff gage and transducer readings changes over time. A data drift may be detected by graphing the difference between staff gage and transducer readings over the deployment period. If the difference between the two readings increases over time it is likely that data drift occurred. If the difference between the two readings suddenly changes and then remains constant over the deployment, it is possible that a data shift occurred due to changing elevation of the transducer relative to the gage.
- **Transducer sensitivity drift.** Sensitivity drift is when the sensitivity of the transducer changes with stage (e.g., the transducer is less sensitive or accurate at high stages). Sensitivity drift may 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 may indicate a sensitivity shift.

If a shift is detected and a follow-up elevation survey is performed, water level 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 (see Figure 16). If there is no gage data for the time period, 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. More detailed information on data drift and correcting datasets can be found in Shedd and Springer (2012).

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.

3.8. Developing Frames of Reference

Following the procedures described above will help measure stream stage. Taken alone, stage measurements yield some information about streamflow patterns, including the timing, frequency, and duration of high flows (McMahon et al. 2003). However, stage data itself does not give quantitative information about the magnitude of streamflows or flow volume, which makes it hard to compare data between streams. Furthermore, the channel shape may change from year to year, such that a similar stage measured in a given location during two separate years may represent different flows. Thus, in order to assess patterns and changes in stream hydrology, it is most useful to convert stage measurements into streamflow.

The most common approach is to use a stage-discharge rating curve. Section 3.8.1 briefly summarizes how to develop a rating curve, with references from the USGS and several state agencies which provide much greater detail on discharge measurement methods and rating curve development. Section 3.8.2 discusses an alternative method which involves less field time, using a combination of channel cross-section measurements and modeling.

3.8.1. Stage-discharge rating curves

A rating curve allows the user to convert stage measurements to streamflow. In order to develop a rating curve, a series of discharge (streamflow) measurements are made at a variety of stages, covering as wide a range of flows as possible. The following discussion summarizes discharge measurements in wadeable streams. Discharge measurement involves measuring the depth and velocity of the water passing through a number of 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. For more detailed guidance consult Rantz et al. (1982), Shedd (2011), or Chase (2005).

3.8.1.1. 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, discharge should be measured at least once annually, and if possible, also after large storms or any other potentially channel-disturbing activities, in order to verify or (if needed) update the curve (see Figure 29 for an example of a channel-disturbing activity). If new measurements are more than 15% off of 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 29. 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.

3.8.1.2. 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 involved includes:

- **Current meters** measure point velocity. There are many different types 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.

3.8.1.3. Site selection

Site selection is critical to making a good discharge measurement. An ideal cross section will have the following characteristics (see Figure 30 for examples):

- A relatively straight stream channel with defined edges and a fairly uniform shape.
- Limited vegetative growth, large cobbles, and boulders.
- 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 30 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 may meet many of the above criteria and provide a good location to measure flow.

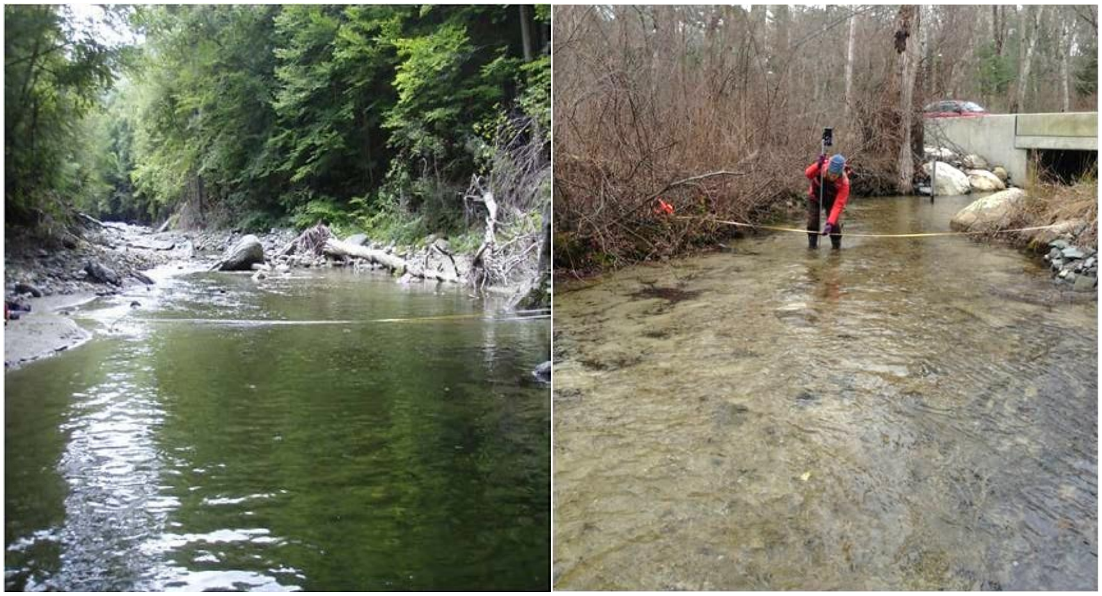


Figure 30. Examples of good cross-sections for making discharge measurements.

3.8.1.4. 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. These points should be distributed such that an approximately equal percent of total flow is in each segment (Figure 31). Thus, measurement points should be closer together in portions of the cross section where flow is more concentrated and depths are greatest and farther apart where the flow is lowest and depths are shallowest. No more than ten percent of the total flow should be within any one segment. Include additional segments where velocity or bottom irregularities are the greatest.

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

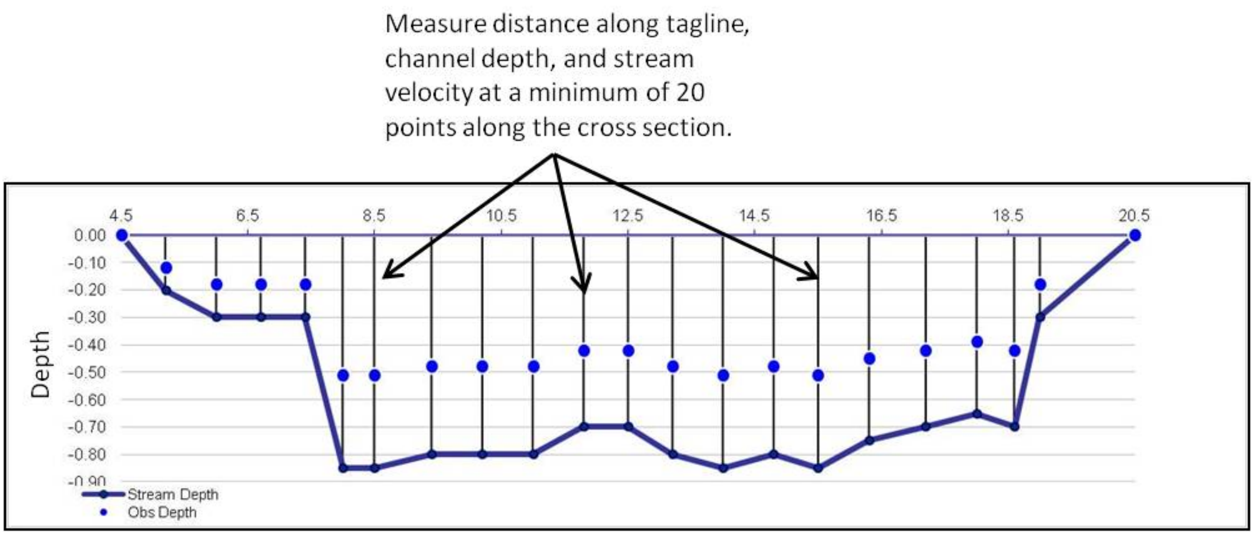


Figure 31. Layout of a channel cross-section for obtaining discharge data, using the velocity-area procedure.

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. It is best to measure the GZF at each discharge measurement, but it may be most practical and effective to locate this point at lower flows.

3.8.1.5. Documentation

At the time of the discharge measurement, take photos 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 (if measured) and location of PZF measurement.

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

3.8.1.6. Quality assurance and control

Careful reading and use of the documents in Section 4 (Literature Cited) is important for good QA/QC of discharge measurements. 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, but be sure that no one is in the stream upstream during measurements, as this will affect the flow readings. The difference between the two measurements should be less than 15%.
- 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 an experienced hydrographer from the USGS or another agency.
- Major, channel-disturbing events (e.g., floods, new culverts) may alter the rating curve. If a major event occurs and subsequent points are not aligned with the original rating curve, a new rating curve may need to be developed and used to convert stage to discharge for points following that event.

3.8.1.7. 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 may 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 32.

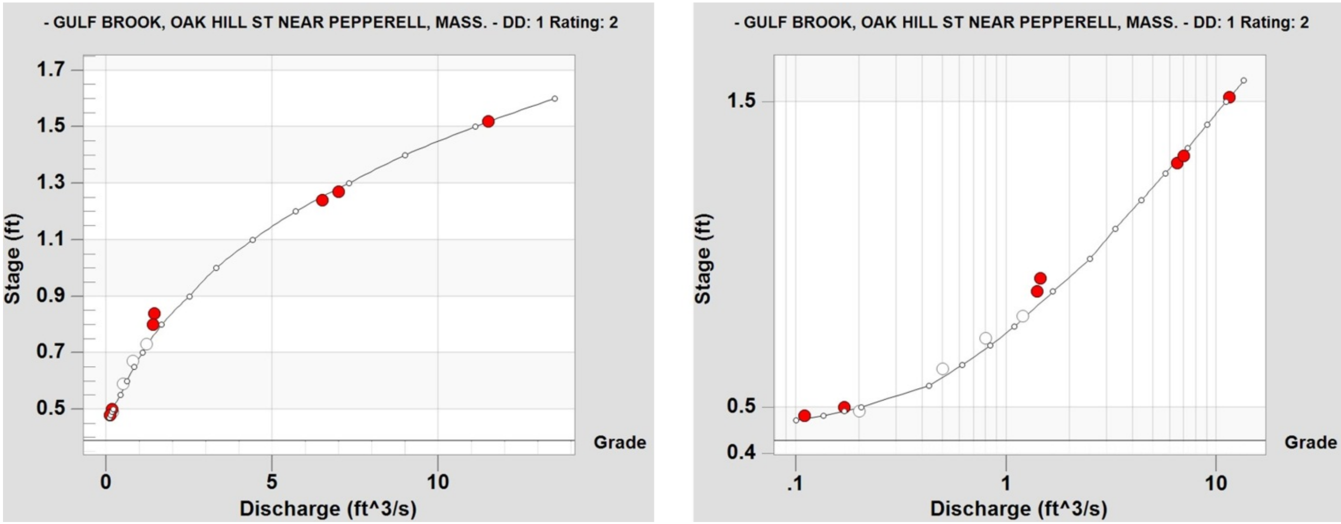


Figure 32. Example of regular (left) and log-log scale (right) rating curves created using Aquatic Informatics' AQUARIUS software.

3.8.2. Channel cross-section measurements and modeling

Converting stage to discharge via a flow rating curve is the best approach for quantifying a wide array of hydrologic indicators that can be compared across time or space. However, for short-term deployments of pressure transducers or sites where making the necessary discharge measurements to develop a rating curve is infeasible, it is possible to calculate stage-based parameters that are referenced to the cross-section where stage measurements are recorded. This approach requires surveying of the cross-sectional profile where the transducer is located, and then modeling the flow to get a mean hydraulic depth for calculating relative measurements of magnitude and volume. This approach was used by Roy et al. (2005) where stage was measured at 30 sites for one year.

3.8.2.1. Equipment

To generate a profile of the channel cross-section, the following equipment is needed:

- An automatic level or electronic total station and tripod, or a clinometer is used to get the height at a consistent level along the cross section.
- A stadia rod is used to measure heights along the cross section.
- A measuring tape and stakes are used to define the exact location of the cross section and measure the widths at which points are measured.

3.8.2.2. Site selection

A profile of the channel cross-section should be made at the precise location of the pressure transducer. The measurements should encompass the entire bankfull width, and have sufficient measurements to get an accurate view of the profile. For stream slope, measurements should be made for the stream reach encompassing the transducer and, if possible, the biotic sampling.

3.8.2.3. Measurements

For the cross section, start by pinning the measuring tape to the left and right banks perpendicular to the streamflow and encompassing the entire bankfull width. If a tripod is being used, place it at a location where the entire width is visible, and where the scope is higher than the highest elevation. Take height measurements along the entire cross section. Be sure to include points at the top and bottom of every break in elevation. More frequent points are necessary where elevation varies. When using an automatic level or tripod, record both the width and the height at each point (an electronic total station will record the height and distance automatically).

For stream slope, take elevation points at riffle tops along a 100-meter reach or longer. If using an automatic level, record longitudinal location (from a tape measure) and height at each point. The electronic total station will capture height and distance automatically at measured points. If the tripod must be moved to view the entire reach, be sure to survey a bench mark and one instream location twice (from each tripod position) and adjust the heights recorded from one tripod location to match the other.

Additional information about measuring cross-sectional profiles and stream slope can be found in Gordon et al. (2004).

3.8.2.4. Documentation

The following data should be recorded:

- Date, time, field crew members.
- Staff gage reading.
- Width, height, and type (water, bank, floodplain) at each recorded location along cross section.
- Longitudinal distance and height for each riffle top for stream slope.
- Bankfull and water width edge locations.
- Picture and hand-drawn sketch of the profile.

3.8.2.5. Quality assurance and control

Ideally, the transducer will be located in a section with high stability and minimal expected changes in the cross-section. However, bed scour and sediment deposition caused by high flows can alter the cross-sectional area and, subsequently, the volume of water associated with certain stages. Thus, the cross-section should be re-surveyed after major events or at least once annually.

3.8.2.6. Modeling

HEC-RAS (US Army Corps of Engineers, Davis, CA) is a freely-available software that can be used to model depths of certain recurrence interval floods based on bankfull cross-sectional area, stream slope, Manning's *n* (a measure of stream roughness), and discharge.

Stream slope should be determined by plotting the riffle-top elevation vs. longitudinal distance; the slope of the linear trendline through the points is the stream slope. Manning's *n* can be visually estimated based on stream type or comparison to photographic keys (Gordon et al. 2004). Discharge for a certain recurrence interval (RI) flood can be determined for each stream based on subcatchment area using published flood-frequency formulas. Roy et al. (2005) related metrics to the 0.5-year RI flood because this level encompassed the mean depth for a majority of the streamflows over the study period. Bankfull cross-sectional area, stream slope, Manning's *n*, and discharge can then be entered into HEC-RAS steady flow analysis to generate a mean hydraulic depth for a certain RI flood at each site.

4. LITERATURE CITED

Bierwagen et al. 2013, in review. Analytical Foundation for a Monitoring Network to Detect Climate Change-Related Effects in Streams in the Northeastern United States

Bilby, R.E. and G.E. Likens. 1980. Importance of organic debris dams in the structure and function of stream ecosystems. Ecology 61: 1107–1113.

Bilhimer, D. and A. Stohr. 2009. Standard Operating Procedures for continuous temperature monitoring of fresh water rivers and streams conducted in a Total Maximum Daily Load (TMDL) project for stream temperature, Version 2.3. Washington State Department of Ecology, Environmental Assessment Program. Available online: http://www.ecy.wa.gov/programs/eap/qa/docs/ECY_EAP_SOP_Cont_Temp_Monit_TMDL_v2_3EAP044.pdf

Butkus, S. 2007. Quality Assurance Monitoring Plan: Streamflow Gaging Network. Washington State Department of Ecology, Environmental Assessment Program. Available online: http://www.ecy.wa.gov/programs/eap/flow/shu_main.html

Chase, R. 2005. Standard Operating Procedure: Streamflow Measurement. Massachusetts Department of Environmental Protection, Division of Watershed Management. CN 68.0.

Division of Ecological Restoration. 2010. River Instream Flow Stewards (RIFLS) Quality Assurance Project Plan. Massachusetts Department of Fish and Game. (Available on-line soon)

City of Salem, OR. 2007. Quality Assurance Project Plan: City of Salem Stormwater Services, Continuous Water Quality Monitoring Program. Available online: http://www.cityofsalem.net/Departments/PublicWorks/Operations/StormwaterServices/Documents/qapp_and_sop_4-07.pdf

Clarke, A., Mac Nally, R., Bond, N. and P.S. Lake. 2008. Macroinvertebrate diversity in headwater streams: a review. Freshwater Biology 53: 1707–1721.

Division of Ecological Restoration. 2010. River Instream Flow Stewards (RIFLS) Quality Assurance Project Plan. Massachusetts Department of Fish and Game. (Available on-line soon).

Dunham, J., G. Chandler, B. Rieman, and D. Martin. 2005. Measuring stream temperature with digital data sensors: a user's guide. Gen. Tech. Rep. RMRSGTR-150WWW. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 15 p. Available online: ttp://fresc.usgs.gov/products/papers/1431_Dunham.pdf.

Durance I. and S.J. Ormerod. 2007. Climate change effects on upland stream macroinvertebrates over a 25-year period. Global Change Biology 13: 942–957.

Fulford, J.M., K.G. Thibodeaux, and W.R. Kaehrle. 1994. Comparison of Current Meters used for Stream Gaging. Proceedings of the Symposium on Fundamentals and Advancements in Hydraulic Measurements and Experimentation, Buffalo, NY. Available online: http://water.usgs.gov/osw/pubs/CompCM.pdf

Gill, G.C. 1979. Development of a small rugged radiation shield for air temperature measurements on drifting buoys. Report to NOAA Data Buoy Office for Development Contract #01-7-038-827 (IF). Bay, St. Louis, MO.

Gordon, N.D., T.A. McMahon, B.L. Finlayson, C.J. Gippel, and R.J. Nathan. 2004. Stream hydrology: an introduction for ecologists. Second edition. John Wiley and Sons, Hoboken, NJ.

Hill, R.A., Hawkins, C.P. and D.M. Carlisle. 2013. Predicting thermal reference conditions for USA streams and rivers. Freshwater Science 32(1): 39-55.

Holden, Z.A., Klene, A., Keefe, R. and G. Moisen (in press). Design and evaluation of an inexpensive solar radiation shield for monitoring surface air temperatures. Agricultural and Forest Meteorology.

Holden, Z.A., Abatzoglou, J., Luce, C. and L.S. Baggett. 2011. Empirical downscaling of minimum air temperature at very fine resolutions in complex terrain. Agricultural and Forest Meteorology.

Holden, Z. 2010. Temperature Sensor Installation Instructions. Available online: http://www.fs.fed.us/rm/boise/AWAE/projects/stream_temp/blogs/06ThoughtsOn%20monitoringAirTemperaturesInComplexForestedTerrain.pdf

Isaak, D. J.; Horan, D. L.; and Wollrab, S. P. 2013. A Simple Protocol Using Underwater Epoxy to Install Annual Temperature Monitoring Sites in Rivers and Streams**.** Gen. Tech. Rep. RMRS-GTR-###. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. ## p. Available online: http://www.fs.fed.us/rm/boise/AWAE/projects/stream_temp/downloads/2013_StreamSensorEpoxyProtocol_RMRS_GTR.pdf

Isaak, D. J. and D.L. Horan. 2011. An assessment of underwater epoxies for permanently installing temperature in mountain streams. North American Journal of Fisheries Management 31: 134-137. Available online: http://www.treesearch.fs.fed.us/pubs/37476.

Isaak, D.J., S. Wollrab, D. Horan, and G. Chandler. 2012. Climate change effects on stream and river temperatures across the northwest U.S. from 1980 – 2009 and implications for salmonid fishes. Climatic Change 113:499-524. Available online: http://www.treesearch.fs.fed.us/pubs/39783.

Jackson, J.K., and L. Fureder. 2006. Long-term studies of freshwater macroinvertebrates – a review of the frequency, duration, and ecological significance. Freshwater Biology 51: 591-603.

Jones, N.E. and B. Schmidt. 2012. ThermoStat Version 3.0: Tools for Analyzing Thermal Regimes. Ontario Ministry of Natural Resources, Aquatic Research and Development Section. Available online: http://people.trentu.ca/nicholasjones/thermostat.htm.

Karl, T.R., J.M. Melillo, and T.C. Peterson, (eds.). 2009. Global Climate Change Impacts in the United States. Cambridge University Press, 189 pp. Available online: http://www.globalchange.gov/publications/reports/scientific-assessments/us-impacts.

Kaushal, S. S., G. E. Likens, N. A. Jaworski, M. L. Pace, A. M. Sides, D. Seekell, K. T. Belt, D. H. Secor, and R. L. Wingate. 2010. Rising stream and river temperatures in the United States. Frontiers in Ecology and the Environment 9:461–466.

Kennedy, E.J. 1984. Discharge Ratings at Gaging Stations. Techniques of Water Resource Investigations of the USGS, Book 3: Applications of Hydraulics, Chapter A10. Available online: http://pubs.er.usgs.gov/publication/twri03A10.

Kennen, J.G., D.J. Sullivan, J.T. May, A.H. Bell, K.M. Beaulieu, and D.E. Rice. 2011. Temporal changes in aquatic-invertebrate and fish assemblages in streams of the north-central and northeastern U.S. Ecological Indicators 18: 312-329.

Larsen, D., P. Kaufmann, T. Kincaid and N. Uruquhart. 2004. Detecting persistent change in the habitat of salmon-bearing streams in the Pacific Northwest. Canadian Journal of Fisheries and Aquatic Sciences 61: 283-291.

Maryland Department of Natural Resources. (nd). Quality Assurance Document for Temperature Monitoring. Draft Version 1.3. Available online: http://www.dnr.state.md.us/streams/pdfs/QA_TemperatureMonitoring.pdf

Mauger, S. 2008. Water temperature data sensor protocol for Cook Inlet salmon streams. Cook Inletkeeper, Homer, Alaska. 10 p. Available online: http://inletkeeper.org/resources/contents/water-temperature-data-sensor-protocol

Mazor, R.D., Purcell, A.H., and Resh, V.H. 2009. Long-term variability in benthic macroinvertebrate bioassessments: A 20-year study from two northern Californian streams. Environmental Management 43: 1269-1286.

McMahon, G., J.D. Bales, J.F. Coles, E.M.P. Giddings, and H. Zappia. 2003. Use of stage data to characterize hydrologic conditions in an urbanizing environment. Journal of the American Water Resources Association 39: 1529-1536.

Meyer J.L., Strayer D.L., Wallace J.B., Eggert S.L., Helfman G.S. and N.E. Leonard. 2007. The contribution of headwater streams to biodiversity in river networks. Journal of the American Water Resources Association 43: 86–103.

Mohseni, O., Stefan, H.G. and T.R. Erickson. 1998. A nonlinear regression model for weekly stream temperatures. Water Resources Research 34(10): 2685-2692.

Rantz, S.E. et al. 1982. Measurement and Computation of Streamflow, Volume I: Measurement of Stage and Discharge and Volume II: Computation of Discharge. USGS Water Supply Paper 2175. Available online: http://water.usgs.gov/pubs/wsp/wsp2175/

Rieman, B. E., and D. J. Isaak. 2010. Climate change, aquatic ecosystems and fishes in the Rocky Mountain west: implications and alternatives for management. U.S. Forest Service, Rocky Mountain Research Station, GTRRMRS- 250, Fort Collins, Colorado.

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

Shedd, J. R. 2011. Standard Operating Procedure for Measuring and Calculating Stream Discharge. Washington State Department of Ecology, Environmental Assessment Program. Available online: http://www.ecy.wa.gov/programs/eap/quality.html

Shedd, J.R. and C. Springer. 2012. Standard Operating Procedures for Correction of Continuous Stage Records Subject to Instrument Drift, Analysis of Instrument Drift, and Calculation of Potential Error in Continuous Stage Records. Washington State Department of Ecology, Environmental Assessment Program – EAP No. EAP082. Available at: http://www.ecy.wa.gov/programs/eap/qa/docs/ECY_EAP_SOP_CorrectionOfContinuousStageRecords_v1_0EAP082.pdf

Sidle R.C., Tsuboama Y., Noguchi S., Hosoda I., Fujieda M. and T. Shimizu. 2000. Stormflow generation in steep forested headwaters: a linked hydrogeomorphic paradigm. Hydrological Processes 14: 369–385.

Sowder, C., and E. A. Steel. 2012. A note on the collection and cleaning of water temperature data. Water 4: 597-606.

U.S. Forest Service, Rocky Mountain Research Station. 2013. Stream Temperature Modeling and Monitoring [web page]. Available online: http://www.fs.fed.us/rm/boise/AWAE/projects/stream_temperature.shtml

Vannote, R.L., Minshall, G.W., Cummins, K.W., Sedell, J.R. and C.E. Cushing. 1980. The River Continuum Concept. Canadian Journal of Fisheries and Aquatic Sciences 37: 130–137.

Ward, W. 2003. Continuous Temperature Sampling Protocols for the Environmental Monitoring and Trends Section. Publication No. 03-03-052. Washington State Department of Ecology Environmental Assessment Program. Available online: https://fortress.wa.gov/ecy/publications/publications/0303052.pdf.

Ward, W. 2011. Standard Operating Procedures for Continuous Temperature Monitoring of Fresh Water Rivers and Streams, version 1. Washington State Department of Ecology Environmental Assessment Program. Available online: http://www.ecy.wa.gov/programs/eap/qa/docs/ECY_EAP_SOP_Cont_Temp_Mon_Ambient_v1_0EAP080.pdf

Wipfli, M.S., Richardson, J.S. and R.J. Naiman. 2007. Ecological linkages between headwaters and downstream ecosystems: transport of organic matter, invertebrates, and wood down headwater channels. Journal of the American Water Resources Association 43: 72–85.

Zimmerman, C.E. and J.E. Finn. 2012. A Simple Method for In Situ Monitoring of Water Temperature in Substrates Used by Spawning Salmonids. Journal of Fish and Wildlife Management 3(2): 288-295. Available online: http://www.fwspubs.org/doi/pdf/10.3996/032012-JFWM-025.