Stream RMN Protocol Document
Temperature (12/29/2022)

Table of Contents

Acknowledgements:
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Background

This document provides a shorter, abbreviated, updated version of the USEPA 2014 “Best Practices” report. It is intended for a wide audience, ranging from people who have deployed sensors and want to review the protocols before going out into the field, to someone who has no prior experience working with temperature sensors and wants to know what it would take to get started (level of effort, equipment needs and costs, protocols, data management). This is a ‘living document’, meaning future updates and improvements will be made as we receive feedback from people who are testing these protocols.

1 Level of effort

The RMN framework allows for different levels of effort to maximize participation. Table 1 contains a ‘menu’ of options for temperature measurements, divided into three levels of participation: ‘minimum’, ‘target’ and ‘best’. At a minimum, water temperature measurements should be taken seasonally at 60-minute intervals (or less). If resources permit, participants are encouraged to collect data at the ‘target’ or ‘best’ levels, since these higher levels of effort increase the number of ways in which the data can be used and improve the likelihood of detecting trends over shorter time periods (this is particularly evident if trends are subtle (USEPA 2016)). The ‘target’ level calls for deploying both air and water temperature sensors year-round[1] and recording data at 30-minute intervals (or less). Together, the air and water temperature data can be used to gain a better understanding of the responsiveness of stream temperatures to air temperatures (also referred to as thermal sensitivity) and provide insights into the factors that influence the vulnerability of streams to thermal change. Air temperature readings are also used for quality control (e.g., to determine when water temperature sensors are dewatered; Bilhimer and Stohr 2009; Sowder and Steel 2012). The highest level of participation calls for deploying multiple water temperature sensors to measure reach-scale variability, but this is optional.

[1] In places where streams become completely frozen during the winter, sensors may be removed during winter months if freezing will result in damage to the equipment. However, based on feedback we have received so far, the temperature sensors that most RMN partners are currently using can withstand being frozen into the ice.

Table 1. Temperature measurements are divided into three levels of participation: ‘minimum’, ‘target’ and ‘better’. Participants are encouraged to collect data at the ‘target’ or ‘best’ levels. Higher levels of effort increase the likelihood of detecting trends over shorter time periods and increase the number of ways in which the data can be used. Note that there may be participation levels that fall in-between those suggested in this table.

Component	Level of participation		
	Minimum	Target	Best
Equipment	Water temperature sensor only	Air and water temperature sensors	Air temperature sensor plus multiple water temperature sensors
Recording interval	Every 60-minutes	Every 30-minutes (or less)	
Deployment period	Growing season (starting before leaf-out)	Year-round	

*monitoring temperature early in the growing season (late April – early May in mid-Atlantic) before leaf-out can capture solar influence (no leaves) on relatively warm days in May, which can cause very warm maximums, and the most extreme magnitude of “swings” during the year, during a “sensitive” ecological period. E.g., fry, spawning, emergences, etc.

2 Protocols

The use of consistent and comparable methods is very important for the RMNs, as different methodologies may introduce analytical constraints and contribute to variability, which reduces the sensitivity of indicators and increases trend detection times. The ‘target’ level of participation calls for deploying both air and water temperature sensors year-round and recording data at 30-minute intervals (or less). Sensors are deployed in the same locations over time to minimize the chances of detecting false trends related to movement of the sensor. If the sensor(s) must be moved, this is noted on the field forms.

Anytime you deploy a sensor, there is a risk of the sensor being lost or damaged. While the risks cannot be completely eliminated, steps can be taken to reduce them. The RMN protocols include measures to help minimize these risks[2] and are based on designs that have been tested and successfully used by various entities for multiple years. These include the two options shown in Figure 1 (cable/rebar and underwater epoxy). These designs can be adapted/customized for your own sites as needed. The temperature sensors that most RMN partners are currently using cost $75-145 and have batteries that last about 5 years, but there are other equipment options as well, both cheaper and more expensive.

If you deploy temperature sensors, the basic phases of implementation are similar, regardless of the design:

- Preparations prior to initial deployment
- Initial deployment
- Follow-up visits (maintenance and data downloads)

[2] See Table 10 in the “Best Practices” document (USEPA 2014) for a summary of tips on how to minimize the chance of sensors being lost or damaged.

In the ensuing subsections, we provide recommended steps for each of these phases.

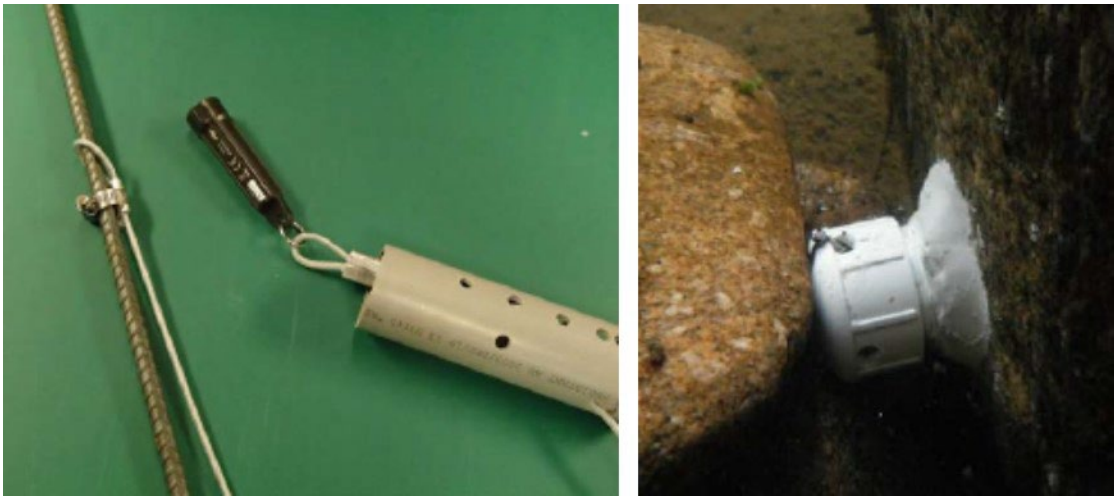

Figure 1. Examples of two design options that have been field-tested successfully for multiple years. The picture on the left (from MDNR) shows a cable and rebar design used in large streams. The picture on the right shows the underwater epoxy design that was pioneered by Dan Isaak and his colleagues at USFS (Isaak and Horan. 2011, Isaak et al. 2013). The sensors are covered by inexpensive PVC shields, which protect the sensors and serve as radiation shields.

2.1 Pre-deployment preparations

Before deploying the sensors, we recommend that you perform the following tasks:

- Site reconnaissance
- Pre-deployment sensor checks
- Sensor configuration and launch

2.1.1 Site reconnaissance

If possible, we recommend that you perform site reconnaissance in advance of deploying the sensors. Photos in particular are very helpful. The water temperature sensor should be located in an area that is representative of the characteristics of the area where biological data are being collected (but the sensor need not be sited in the exact same location). The more of the following information you can gather, the better chance you'll have for a successful deployment -

- Do you need to obtain permission to access and/or do the installation at the site? If so, what does that entail?
- What is the range of flow conditions the location is likely to experience?
    - How low does the water get during baseflow conditions? Is there enough depth to keep the sensor submerged year-round?
    - How high are the flows likely to get?
    - Can the location be safely accessed and waded by crew members year-round? If not, when is the location likely to be inaccessible?
- What is the gradient of the reach? Avoid reaches with very high gradients (>7%) because sensor retention rates are inversely related with slope (Isaak et al. 2013).

- What kind of attachment points are available? Will you be attaching the sensor to a natural object (e.g., in the streambed or to a tree along the bank)? Or is there an existing, permanent structure (like a bridge) that you can attach the sensor to?
- How stable (or unstable) are the bottom substrates?
- What level of human activity occurs at the site? How big a concern is vandalism? Can the sensor be adequately hidden or camouflaged? Is wildlife going to be a problem?
- What types of flow habitats occur in the reach? (runs and pools are preferred installation sites over riffles).
- Is the water well-mixed? In general, any moving water will be well-mixed but it's good to doublecheck by taking numerous instantaneous temperature measurements near potential deployment locations. If these measurements exhibit a high degree of variability, avoid those areas.
- Does the stream freeze completely during the winter (from top to bottom) or is there flowing water year-round at the lower depths?
- Do any of the following influence the site? If so, try to avoid these areas -
    - beaver activity
    - a tributary confluence
    - an impoundment (including beaver ponds)
    - a lake outlet
    - point-source discharges
    - streamside wetland areas
    - hot springs
    - groundwater seeps

2.1.2 Sensor accuracy check (pre-deployment)

Verify that the temperature sensors are meeting the accuracy quoted by the manufacturer, have sufficient battery life and are launching and downloading data properly (better to find out in the lab vs. finding out when you do your first data download months after deploying the sensors). Sensors with low battery levels should be removed from circulation. Another good reason for performing these checks is to familiarize yourself with the equipment.

Perform either single- or multi-point accuracy checks to verify that the sensors meet the accuracy quoted by the manufacturer. Compare the sensor readings to a National Institute of Standards and Technology (NIST)-calibrated thermometer; they should not exceed the accuracy quoted by the manufacturer (e.g., ±0.2°C if you are using the proV2 sensor). Figure 2 shows a commonly-used single-point method called the "ice bucket" method. The sensors are placed in an ice bath for several hours and sensor readings are checked against readings from a NIST-certified thermometer. Sensors that have anomalous readings are set aside for further testing or returned to the manufacturer for replacement. More detailed instructions for single- or multi-point checks can be found in the "Best Practices" document (USEPA 2014).

Maintain documentation of the pre-deployment checks (example data forms can be found in Appendix C in the "Best Practices" document (USEPA 2014)).

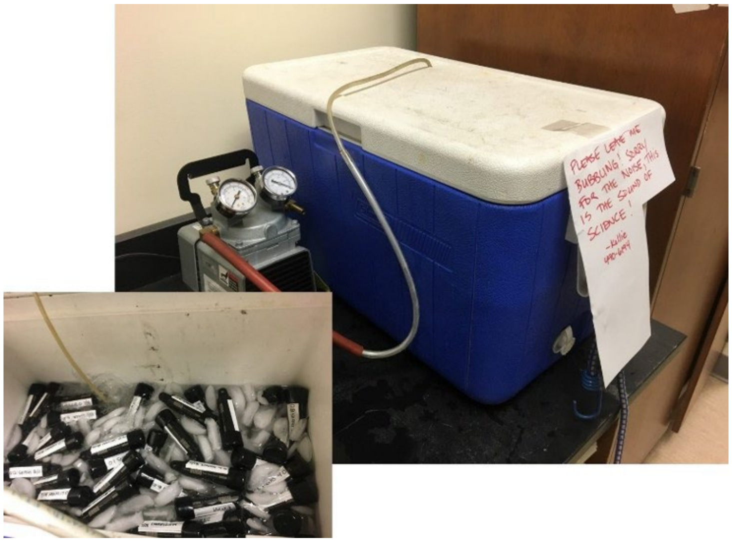

Figure 2. The "ice bucket" method is a commonly-used single-point method for checking accuracy of temperature sensors before deployment. The sensors are placed in an ice bath for several hours and sensor readings are checked against readings from a NIST-certified thermometer. Photos provided by VT DEC.

2.1.3 Sensor launch and configuration

Temperature sensors are configured to record measurements at 30-minute intervals (or less).

To make the data processing steps faster and easier, we recommend that sensors are set up to:
- Record on the hour (xx:00), half hour (xx:30), or quarter hour (xx:15 or xx:45)
- Record in consistent units (for temperature, report in °C)
- Record in military time (if possible)
- Record in local standard time (e.g., UTC-5 for sites in the Eastern Time zone) instead of daylight savings time

During the initial deployment, some people use the "delayed start" feature (if available) so that the sensor doesn't start recording until 1-2 hours after it is in position and has time to stabilize. This saves you from having to potentially remove (or 'trim') the first several data points later on during data processing. On ensuing visits, when you do routine data downloads, you shouldn't have to change the configuration settings (assuming the initial configuration was done correctly).

Make sure air and water temperature sensors are programmed to record at the exact same time. See Text Box #1 for an important note about issues that have arisen with Onset HOBO air and water sensors due to a configuration issue that can easily be avoided. Instructions for launching and configuring Onset HOBO sensors are available on the ContDataQC website (https://nalms.shinyapps.io/ContDataQC/; in the Sensor configuration section of the 'Main Functions' – 'QC tips' tab).

If you are using Onset HOBO sensors, the serial number (S/N) is the default sensor name. When you configure and launch the HOBO sensors, you have the option of renaming the sensor. Some people rename the sensors, others do not. If you rename the sensor, the HOBO software still retains the S/N and allows you to include S/N when you create output files.

IMPORTANT TIME-SAVING TIP: come up with a file naming scheme that works well for your data management system and make sure all personnel use it. For example, if you are using the ContDataQC tool for QCing your data, it's best to follow the recommended file naming scheme from the start (e.g., Long_AW_20190101_20211230), otherwise you'll have to go back and rename files later. For more information on the ContDataQC file naming and formatting scheme, visit the ContDataQC website (https://nalms.shinyapps.io/ContDataQC/) and/or contact Jen.Stamp@tetratech.com.

TEXT BOX #1: Important configuration note

Important! If you are deploying air and water sensors at a site, make sure they are recording at the same time. This will make data processing easier and will improve the quality of your data. Some people have had problems with air and water sensors getting out of sync (e.g., one records at 11:03 and the other records at 11:18).

If you are using the Onset HOBO sensors, this typically happens when the user selects 'Start Logging: Now' and then deploys one sensor and then the other (at that point, recording times are usually spaced about 10-15 minutes apart). Good news! You can easily avoid this by selecting 'Start Logging: At interval' or 'On date/time' (and enter on the hour and half hour if it's a 30-minute logging interval). If you launch the sensor with these settings, the sensor will retain these settings during future downloads and relaunches with waterproof shuttles. If your air and water sensors get out of sync, you will need to bring a laptop into the field (or bring the sensors back to your computer at the lab) and enter the proper settings during the relaunch.

2.2 Initial deployment

Initial deployment involves the following steps:

- Install the sensor
- Take discrete (instantaneous) temperature measurement
- Document the site

2.2.1 Water temperature sensors

We recommend labeling sensors so that passersbys who happen to find your sensor will know it is a temperature sensor. Also include your organization name and contact information. If your organization has specific policies regarding signage, follow those protocols.

2.2.1.1 Placement

Water temperature sensors are deployed in locations with as many of the following characteristics as possible, prioritized in this order:

- In an area that is representative of the characteristics of the area where biological data are being collected (but not in the riffle)
- In areas of well-mixed water

- Of sufficient depth to keep the sensor submerged year-round but not so deep that it can't be accessed year-round (e.g., during spring baseflow)
- Stable substrate unlikely to be buried in sand/silt
- Hidden yet easy to relocate
- Protected from physical impacts associated with high flow events
- Low human activity to reduce vandalism and accidental snagging

Where feasible, water temperature sensors are placed approximately 6 inches above the stream bottom (per Schuett-Hames et al. 1999). If this is not possible and sensors are placed on the stream bottom, crews should note this on the field form. This information is important because the temperature readings could be influenced by groundwater and subsurface flow, and sensors on or near the streambed are more susceptible to burial by moving substrates (sensors should never be intentionally buried).

If conditions permit, install sensors on the downstream side of the structure to which the sensor is being attached (e.g., a large rock or log). Doing so will help protect the sensor from high water velocities and associated substrate movement and transport of debris that commonly damage or dislodge sensors. Ideally, the structure will also hide the sensor from potential vandals. Another important consideration is accessibility. Whenever possible, pick a location that is on the same side of the stream as your access point. Otherwise you may not be able to retrieve your sensor during periods of high flows.

2.2.1.2 Installation

Techniques for deploying the water temperature sensors vary depending on many factors. All have pros and cons. Site-specific conditions will dictate which installation technique is most appropriate. Here we briefly describe two installation methods: the underwater epoxy method (Isaak and Horan 2011, Isaak et al. 2013) and a method in which sensors are cabled to rebar or stable instream structures such as large rocks or boulders, woody debris, or roots (Mauger 2008, Ward 2011) (see Figure 1). When you do the installation, consider doing so during low flow conditions – this enables field personnel to check whether the water is well-mixed and of sufficient depth. In the Northeast, field crews generally find late summer/early fall (when flows are typically lowest) to be the best time to do installations. However, this is not a requirement.

The underwater epoxy method can be used in multiple environments provided a suitable anchor point is available, such as a large rock or cement structure (e.g., bridge support). 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. After selecting an attachment point, use epoxy to attach the sensor and shield to the structure, and lean a rock against the face of the PVC canister to hold it in place while the epoxy sets (Figure 1 - right). Use of a specific underwater epoxy is critical to the success of this method. Once the epoxy sets, it will hold the sensor across the full range of annual and daily water temperatures. Detailed instructions are available in the "Best Practices" document (USEPA 2014) (this includes an equipment list and the step-by-step procedure). There is also a YouTube video: http://www.youtube.com/watch?v=vaYaycwfmXs&feature=youtu.be

Another design option is to cable the sensor and shield to rebar or stable instream structures like large rocks or boulders, roots, or woody debris. If site conditions permit, attach the sensors to the downstream side of the instream structure, as this will shield the sensor from moving rocks or debris during floods. Use heavy duty (e.g., 120-lb tensile strength) cable ties or wire to attach the sensors to the structures. If conditions permit, attach the sensor at two points. If you think the structure might move during high flow events, consider cabling or chaining the structure to an object on the nearest bank (or to another stable instream structure). If a site lacks these types of stable instream structures and the stream bottom is such that a metal stake can be driven into it (e.g., no near-surface bedrock or consolidated sediments), the rebar method can be used. More detailed instructions can be found in the "Best Practices" document (USEPA 2014).

Appendix D of the "Best Practices" document (USEPA 2014) describes alternate types of installation techniques. Also, the RMN stream network now includes some sites in low gradient, soft-bottom streams that are not covered in the USEPA (2014) document. Figure 3 shows a picture of a technique that RMN Partners in the Midwest (EPA Region 7) have been using with mixed success. They are pounding a metal fence post into the streambed at an angle, like shown in the photo, and attaching sensors to the post. Nebraska started using 2 fence posts instead of one (with one upstream to take the initial hit from a debris flow, and the second fence post (with the sensor) just downstream, which has saved some of their sensors from debris during high flow events.

Figure 4 shows another low gradient installation technique. It is being used by Vermont DEC in small, low velocity, rocky or soft-bottom streams. The sensor is housed in a PVC shield that is attached to a cinder block with stainless steel cable, about 8" off the stream bottom (which helps prevent the sensors from being buried in sediment, which is a problem that some RMN partners are having). EPA Region 3 and Missouri have also used concrete blocks with success, anchoring them down with 2-ft pieces of rebar, or to structures along the bank. If there aren't suitable structures along the bank, Minnesota has had success with tie-down (corkscrew) stakes or anchors (e.g., see examples from dog or aircraft tie-down kits).

Additional installation techniques can be found in the recent USGS/NPS publication titled 'Monitoring Stream Temperature – A Guide for Non-Specialists' (https://pubs.usgs.gov/tm/03/a25/tm3a25.pdf).

Figure 3. Installations in low gradient, soft-bottom streams require different techniques. RMN partners in the Midwest (EPA Region 7) have been pounding a metal fence post into streambeds at an angle, as shown here, and attaching sensors to the post.

Figure 4. An installation technique that has been used successfully in small, low velocity, hard or soft-bottom streams involves attaching PVC housing to a cinder block with a stainless-steel cable, and then a placing a TidbiT sensor inside the housing. The cinder block keeps the sensor ~8" off the stream bottom, which helps prevent sensors from being buried in sediment. Photos were provided by Aaron Moore, VT DEC.

2.2.2 Air temperature sensors

We recommend labeling sensors so that passersbys who happen to find your sensor will know it is a temperature sensor. Also include your organization name and contact information. If your organization has specific policies regarding signage, follow those protocols.

2.2.2.1 Placement

Air temperature sensors are placed in suitable areas that are as close to the water temperature sensor and biological sampling area as possible. The location of the air temperature sensor in relation to the water temperature sensor should remain constant throughout the period of data collection. To be consistent with typical meteorological observations, air temperature sensors are placed at a height of 2 meters, or approximately 6 feet, off the ground, out of direct sunlight if possible. If the riparian area is forested, mount the air temperature sensor to the north-facing side of a tree. Because trees, vegetation, and the ground create radiation microenvironments, try to minimize the amount of other vegetation near the sensor. If suitable trees are not available, attach the sensor to the north side of an existing or constructed stable structure (e.g., fence post). Make efforts to hide the sensors from view to reduce the chance of vandalism.

2.2.2.2 Installation

Site-specific conditions and the type of radiation shield you are using (see Figure 5 for two examples) will dictate which installation technique is most appropriate for the air temperature sensors. The "Best Practices" document (USEPA 2014) describes how to make a radiation shield and includes a four-step process on how to do the installation. If there is an existing structure (like a tree or fence post), you'll need to customize the installation to fit that structure. If trees or other suitable, stable existing structures (e.g., fence posts) are absent, the "Best Practices" document (USEPA 2014) describes how to construct a PVC pipe structure and mount the sensor to the pipe. If you are not using a waterproof air temperature sensor, make sure the sensor is installed in a way that protects it from the elements.

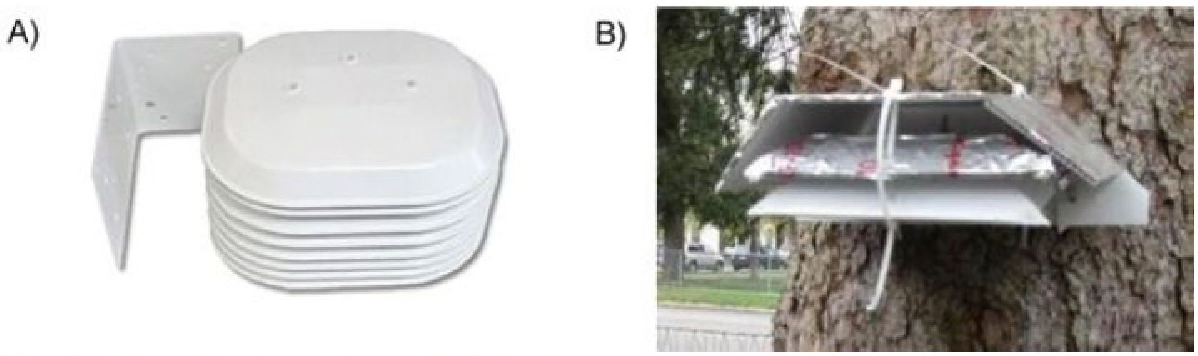

Figure 5. Examples of radiation shields for air temperature sensors include A) the Gill-style Onset RS1 solar radiation shield (www.onsetcomp.com) and B) custom design by Zachary Holden (for more information, see Section 4.2). Based on feedback from RMN partners, Design (A) holds up better over time and several partners are replacing Design (B) with Design (A) or something comparable.

2.2.3 Discrete (instantaneous) temperature measurements

Discrete water temperature measurements should be taken during each site visit (with a calibrated instrument) since they are used for QA/QC checks. After the water temperature sensor is correctly positioned, take a discrete/instantaneous measurement with a NIST-calibrated thermometer as close as possible to the sensor and as close as possible to the time when the sensor is recording a measurement. Ensure that sufficient time has passed to allow the field thermometer to stabilize before recording the measurement. This measurement is used to help determine when the temperature measurements from the sensor stabilize. The measurements that occur during the stabilization period are later removed or 'trimmed' during data processing. To avoid trimming temperature data, some organizations use the 'delayed launch' feature to configure the sensor to start recording measurements several hours after deployment (which allows time for the sensor measurements to stabilize). The discrete/instantaneous measurement is recorded on a sensor tracking form like the one shown in Appendix D of the "Best Practices" document (USEPA 2014).

We recommend taking a similar measurement for the air temperature sensor, but this is optional since it is very difficult to obtain a stable, accurate air temperature measurement in the field.

2.2.4 Documentation

It is critical to document the location of the sensors to the best of your ability so that you (or others) can relocate the sensors after initial deployment (one of the most common reasons for the loss of temperature sensors is failure to relocate the sensor after initial field deployment). To improve the chances of successfully retrieving your sensors, we recommend that you -

- 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 (see example in Figure 6). Archive photos in a central database for future use.
- Make detailed hand-drawn maps with landmark references (e.g., unique rock, log, root, flagging, or tree), sensor locations, direction of stream flow, places to park, paths to the stream, and any other characteristics that might be appropriate, annotate photographs when viewing them later on a computer, or both. As much as possible, include precise distances from "permanent" landmarks to sensors (e.g., 38 m downstream of bridge, 2.2 m upstream of overhanging, multi-stemmed sycamore on left bank).
- Complete a field form like the one shown in Appendix D of the "Best Practices" document (USEPA 2014).

Based on feedback we've received from RMN partners, we recommend labeling the sensors so that passerbys who happen to find them know they are temperature sensors. We also recommend including your organization name and contact information. If your organization has specific policies regarding signage, follow those protocols.

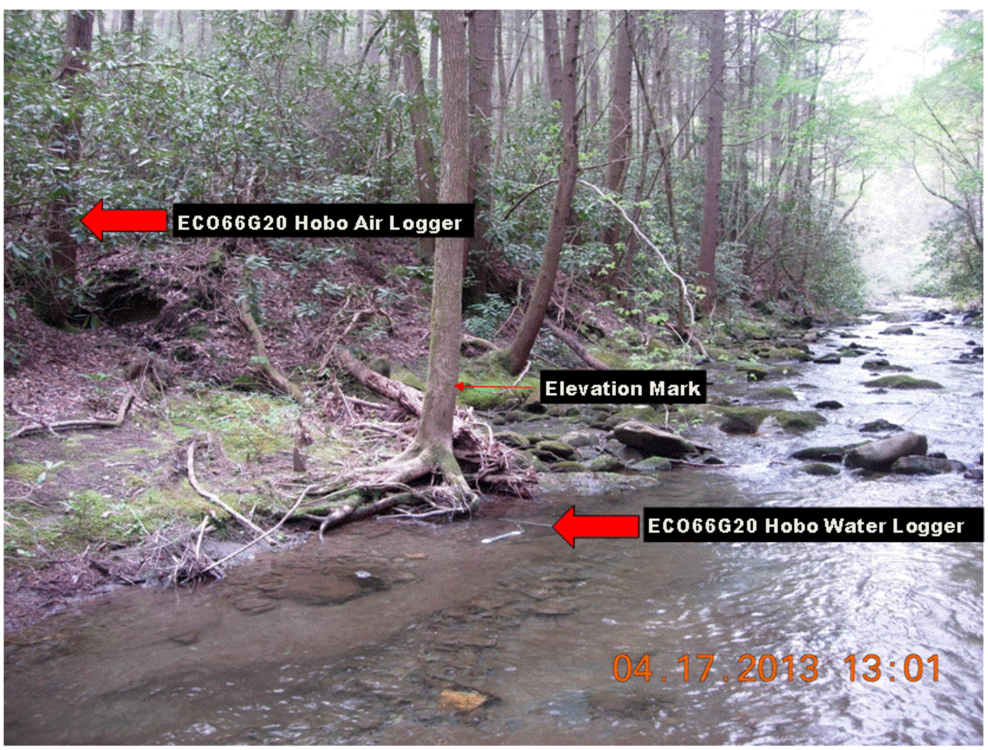

Figure 6. Site documentation provided by Virginia DEQ.

2.3 Follow-up visits

After doing the initial deployment, there is flexibility in the timing of follow-up visits, especially if you are only collecting temperature data. At a minimum, temperature data should be downloaded once a year but more frequent site visits help ensure the longevity of the sensors and data quality (and if there is a problem, you'll lose less data). Northeast partners typically do site visits/data downloads in the spring and fall. The spring is typically when most sensors are lost in the Northeast due to high flows. In the Southeast, some partners are doing quarterly visits, at which time they also take discrete measurements for accuracy/QC checks and collect water chemistry data.

Follow-up visits (after initial deployment) involve the following basic steps:

- Prepare equipment
- Locate the sensors
- Take discrete temperature measurements
- Retrieve/download/perform maintenance as needed/redeploy
- Document/complete field forms

2.3.1 Prepare equipment

We recommend that you put together a checklist and always go through it before leaving the office and heading into the field. If you are using Onset HOBO sensors, make sure the software in your data offload device (either a base station & laptop or waterproof shuttle – see Section 4.3) is up to date. The waterproof shuttle is used by most field crews. Be sure to check the batteries, save any data that were on the shuttle, update the shuttle firmware (if needed - http://www.onsetcomp.com/support/firmware_updates), and sync it with a computer that is set to the correct time/date. Failure to complete these steps can contribute to data loss. IMPORTANT TIP: remove batteries from the HOBO waterproof shuttle if it's not being used for prolonged periods. Some partners have recently had shuttles fail due to corrosion while sitting.

Bring extra sensors (if available) in case you need to replace any. If you replace a sensor, be sure to document the change-out.

2.3.2 Locate the sensors

Finding the sensor can be challenging. To improve your chances of finding the sensors -

- Before going to the site, review photos and maps from the initial documentation.
- Use a GPS unit in combination with the maps and photos to navigate to the site (the higher the accuracy of the GPS unit, the better).

Some people have used metal detectors to help find their sensors, but this only works if the sensors are attached to metal (e.g., metal clamps, rebar).

2.3.3 Discrete (instantaneous) temperature measurements

Before you remove the water temperature sensor to download data, take a discrete/instantaneous temperature measurement with a NIST-calibrated thermometer, as close as possible to the sensor and as close as possible to the time when the sensor is recording a measurement. Ensure that sufficient time has passed to allow the field thermometer to stabilize before recording the measurement[3]. Record the measurement on a field form like the one shown in Appendix D of the "Best Practices" document (USEPA 2014). The discrete measurement will be used later for a sensor accuracy check (see Section 4).

We recommend taking a similar measurement for the air temperature sensor, but this is optional since it is very difficult to obtain a stable, accurate air temperature measurement in the field.

2.3.4 Sensor download and maintenance activities

Barring technical (or other unforeseen) difficulties, experienced field crews are typically able to download data and return the sensor into position in 15-20 minutes. Some field crews time their visits to correspond with sensor measurements times, such that they arrive at the site and retrieve the sensor shortly after a measurement has occurred (e.g., on the hour or half-hour if you are using a 30-minute recording interval). This is encouraged when possible but is not necessary. During data processing/QC, the first several post-download measurements should be carefully examined for outliers or signs that the sensor had not yet stabilized (and if not, those data points should be flagged and excluded from analyses).

To download data, follow the sensor manufacturer's instructions and use the appropriate device(s). If you download the sensor data in the field, follow the manufacturer's instructions and use the appropriate device(s). As you're working with the sensors, perform the checklists shown in Table 2. Throughout this process, take careful notes. Be sure to record the time during which the sensor was out of position for data download (this is important to know for data QA/QC). If you see anything that could affect the accuracy of the measurements, make a note about it on the field form (e.g., was the sensor where you expected to find it or were there signs of movement? any signs of fouling, disturbance or vandalism?). Photos are very helpful for documentation as well. Once the data download is complete, return the sensors to the same location as before (or as close as possible).

If you are using Onset HOBO sensors, instructional materials on downloading data are available upon request (email Jen.Stamp@tetratech.com). The HOBO waterproof shuttle is easier to work with in the field than the base station (which is not waterproof and requires a laptop with HOBOWare software). The shuttle needs to be shaded during the download (it uses infrared light to transfer data and may not work properly if it's in direct sunlight). A downside of the HOBO waterproof shuttle is that you won't be able to view battery life or the data files until after they've been transferred from the shuttle to a computer with HOBOWare. IMPORTANT TIP: check the datafile soon after downloading if you don't bring a computer into the field. Sometimes problems occur during the download (e.g., the downloading interval has somehow gone awry or the dates are messed up) which may result in the need for an additional site visit.

If you are unable to locate your sensor and have a replacement with you, install the new sensor in the same place where the previous sensor had been located (or as close as possible; pending safety and suitability issues; if sensors are continually being lost from that location, try a new one). Depending on the timing of your visit, you could do a permanent or temporary installation. For example, when VT DEC loses sensors, it typically occurs during spring high flows, which is not a safe or suitable time to do a

[3]Some partners have had issues with what seems to be clock-drift with HOBO sensors; therefore, they take discrete measurements at interval (top or bottom of hour) but wait at least 10 minutes to ensure the sensor records the corresponding measurement.

permanent installation. To minimize data loss, they usually do a temporary installation using the cinder block method shown in Figure 4, and then return in the late summer/early fall (when flows are typically lowest) to do a permanent reattachment.

Table 1. Checklists for performing maintenance/mid-deployment checks and data downloads.

Task	**Procedure**
Maintenance/ mid-deployment checks	• Check the security of the housing and deployment equipment and adjust if necessary. • Look for signs of physical damage, vandalism, or disturbance. • Ensure that the sensor is submerged. If it is not, move it to a location where it is covered by water and will remain so during periods of base-flow. • Ensure the sensor is not buried in sediment. If it is, remove the sediment and reinstall the sensor where it will not be buried during future high flow events. Note on the datasheet that the sensor was buried because temperature recordings are likely to be significantly biased toward cooler temperatures by hyporheic flows. In many cases, temperature recordings from buried sensors should be discarded because of high bias and because accurate adjustments are difficult to apply. • Remove anything that could bias the temperature readings (e.g., debris, aquatic vegetation, algae). Note: if sensors have protective housings with fine screens or small flow-through holes, they can be easily fouled in eutrophic systems with abundant periphyton or algal growth. • Take photos to document any changes to the monitoring location (particularly those that could influence readings). • Take instantaneous stream temperature measurements at the location of the sensor with a NIST-calibrated field thermometer. *Note: this measurement should be taken as close as possible to the time when the sensor will be recording a reading*. • Record observations on the field form (like the example shown in Appendix G of USEPA 2014). • OPTIONAL: Biofouling check. Remove the sensor and gently clean it (per manufacturer's instructions) to remove any biofilm or sediment, then return the cleaned sensor to the stream. Note on your field form the time the 'pre-cleaning' measurement was made and the time of the first 'post cleaning' measurement. Compare the readings.
Data offload	• Before connecting the sensor to the data offload device, gently wipe the sensor with a soft wet cloth or soft bristled brush to remove any biofilm or sediment that could affect its ability to connect. • Attach the sensor to a base station or shuttle and then connect the data offload device to a computer with the appropriate software. • Once the connection is established, follow manufacturer's downloading procedures. • Clear the sensor memory as necessary to ensure sufficient capacity for continued deployment.

Sensor retrieval	• If a sensor is removed from a site, before leaving the site, mark it with a temporary tag identifying the site, date, and time of retrieval. • Be sure to record the exact times of deployment (in proper position) and recovery. This information is needed for trimming data after retrieval.

3 Quality Assurance/Quality Control (QA/QC)

QA/QC is a critical component of monitoring, as it ensures data quality objectives are being met. This section contains recommended QA/QC procedures for taking temperature measurements with continuous sensors at RMN sites. If you already have existing approved Standard Operating Procedures (SOPs) and/or QAPPs and they meet these minimum requirements, keep collecting data in accordance with your approved methods. Oversight and compliance are left up to RMN participants.

Roles and responsibilities.
Make sure field crews and people processing the data know their roles, are trained and are familiar with the sensors. If multiple people are working with sensors at different sites, assign an overall lead to make sure that the following tasks get done:

Equipment
- Track status (e.g., battery life[4])
- (if applicable) Ensure the Onset HOBOware software updates are being performed (as needed) on laptop and/or waterproof shuttle before going into the field
- Track problems and needs

Field visits
- Make sure accuracy check measurements are being done
- Make sure data are getting downloaded at least once a year (preferably more)
- Make sure air and water sensors are recording at the same time
- Make sure field crews are taking detailed field notes

Data processing
- Set up an organizational scheme for the data files (folders, file names) and make sure people are adhering to it. If you don't have an existing data management system for continuous data, USEPA and RMN partners have developed guidance and a free R package for QCing and summarizing the continuous temperature data (ContDataQC – https://github.com/leppott/ContDataQC). The R package requires that files be formatted and named a specific way, so if you are planning to use the R package, it's best to start naming and formatting files in accordance with this scheme from the start (vs. having to go back and do it later). For more information, contact Britta Bierwagen (Bierwagen.Britta@epa.gov).
- Make sure the data files are stored in a secure location that gets backed up regularly

[4]Partners have found that the HOBO sensor battery life estimates are sometimes inaccurate (e.g., they may indicate a full battery during a site visit, only for you to find a dead battery when you return).

- After each download, make sure a standard set of procedures are performed to ensure the quality of the data and make necessary corrections (see checklists in Table 3; there is a more comprehensive checklist in Appendix H of USEPA 2014). Make sure the findings are documented.
- Both the original and the cleaned data files should be maintained and archived.
- Any changes you make to the data should be carefully documented, and all forms should be organized, easily accessible, and archived in a way that allows for safe, long-term storage.

Table 3. Error screening procedure (Dunham et al. 2005, Sowder and Steel 2012, Personal communication, Michael Kashiwagi (MDDNR), April 17, 2014, Personal communication, Dustin Shull (PADEP), February 2, 2014)

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

<u>Accuracy checks</u>

Before the sensors are deployed in the field, perform single or multi-point accuracy checks in the lab (see instructions in Section 2.2.1 of the “Best Practices” document (USEPA 2014)) to verify that the temperature sensors are meeting the accuracy quoted by the manufacturer (e.g., ±0.2°C if you are using the proV2 sensor), have sufficient battery life and are launching and downloading data properly (better to find out in the lab vs. finding out when you do your first data download months after deploying the sensors). Sensors with low battery levels and/or that do not meet the accuracy requirements should be removed from circulation.

After the initial installation, during each field visit (assuming the sensor is safely accessible), take discrete (instantaneous) water temperature measurements as described in Section 3.3.3. After the data are downloaded and viewed on a computer, the discrete measurement is matched with the closest sensor measurement and the difference is calculated. The difference should not exceed the accuracy quoted by the manufacturer. If a sensor fails this check, repeat the procedure. If it fails a second time, flag the data with an appropriate data qualifier, and review the field notes to look for comments about situations that could cause the NIST-calibrated field thermometer measurement to be faulty (e.g., perhaps the crew could not take the measurement in close proximity to the temperature sensor due to high flow conditions, or used daylight savings time instead of standard time when recording the time of the measurement). If no issues with the NIST-calibrated field thermometer measurement are documented, consider replacing the sensor. These mid-deployment accuracy checks make the data more defensible and can potentially be used to make corrections (e.g., for sensor drift). They should be performed sooner than later after the data are downloaded (otherwise if there is a problem, the longer the issue goes undetected, the more data is potentially lost).

There is a third type of accuracy check called a post-deployment check. It is optional but encouraged at RMN sites. To perform the check, follow the single or multi-point pre-deployment accuracy check procedures described in Section 2.2.1 of the “Best Practices” document to verify that the sensors meet the accuracy quoted by the manufacturer.

Biofouling check

This check is optional but encouraged at RMN sites. During the field visit, the sensor is removed and gently cleaned (per manufacturer’s instructions) to remove any biofilm or sediment. Then the cleaned sensor is returned to the stream. The time at which the “pre-cleaning” measurement was made and the time of the first “post-cleaning” measurement is noted on the field form, and readings are compared.

4 Equipment

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

- A temperature sensor
- A radiation shield to prevent direct solar radiation from hitting the sensor (this can also serve as a protective housing)
- Installation materials to secure the sensor (e.g., cable, rebar) and identification tags
- (if applicable) A data offload device that is compatible with the model of the sensor
- (if applicable) A computer with software that is compatible with the data offload device

Additional equipment is needed to install the temperature sensors. This is discussed in more detail in the “Best Practices” document (USEPA 2014).

4.1 Sensors

When selecting temperature sensors, consider factors such as durability, accuracy, resolution, measurement range, memory, and battery life. For RMN sites, select sensors that are durable (able to withstand years of use in challenging conditions), have a minimum accuracy of ±0.5°C, capture the full range of expected temperatures, have a memory that is sufficient to record measurements at 30-minute intervals during the deployment period, and have adequate battery life (Table 4). Most RMN partners are currently using the Onset HOBO ProV2 and TidbiT temperature sensors (Figure 6) for both water and air temperature measurements. They both cost around $145 (as of December 2022) and typically last about five years[5] when set to record at 30-minute intervals year-round. They both have an accuracy of ±0.2°C. Some RMN partners are using Onset HOBO U20 series water level sensors (non-vented pressure transducers) to record both temperature and water level. These water level sensors have an accuracy of ±0.5°C and they cost from $330 to $555, depending on the model (as of December 2022). Two non-vented pressure transducers are needed (one goes in the water, the other on land; the one on land measures barometric pressure). For more information on water level sensors, see the Stream RMN Hydrology protocol document. It should be noted that this does not constitute an endorsement or recommendation for the use of any of these sensors; rather it is for descriptive purposes only.

Table 4. Specifications for temperature sensors used in the RMNs

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

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

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

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

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

[5]Cold temperatures can shorten the battery life

Figure 6. The Onset HOBO ProV2 (left) and TidbiT (right) temperature sensors are currently the most commonly-used temperature sensors at RMN streams. This does not constitute an endorsement or recommendation for their use; rather it is for descriptive purposes only.

4.2 Radiation shields

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

The “Best Practices” document (USEPA 2014) contains instructions on how to make PVC shields for water and air temperature sensors (see Appendix A for water temperature sensors and Appendix B for air temperature sensors).

For water temperature sensors, many RMN partners are using a polyvinyl chloride (PVC) canister (see examples in Figure 1), which is simple and inexpensive to construct. 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 are beyond the price range of most RMN partners and require power, passive/non-aspirated designs are more suitable for remote deployment. Some RMN partners are purchasing shields like the one shown in Figure 4A, which cost about $40-50. Others have been using a design developed by Zachary Holden (see Figure 4B), which costs approximately $2.50–3.00 per shield if produced in bulk. Holden tested his design and found that it performed well compared to commercially available shields (Holden et al. 2013). A YouTube video (accessed 15 June 2013) with instructions on how to construct the custom-made shield can be found at: www.youtube.com/watch?v=LkVmJRsw5vs.

4.3 Sensor accessories

In addition to the sensors themselves, depending on the brand, you may need accessories to configure, launch, download and work with the sensor data. Consider compatibility when purchasing equipment. Ensure that the data offload device and software are compatible with the model of the temperature sensor. If purchasing multiple sensors, buying the same model is often the most cost-effective because reduced prices might be available for bulk orders and only one data offload device and one software package are necessary for that particular model of sensor.

If you are using Onset sensors, they require the following additional equipment:

- Onset HOBO download devices (need one or the other) (Figure 6)

  - base station - $140 (as of December 2022)
  - waterproof shuttle - $280 (as of December 2022)
- Proprietary software –
  - Onset HOBOware Pro ($75 online (download only); $99 CD) - the ‘Pro’ version is needed to generate sensor depth or water level (as of November 2019) but the free version should work for temperature alone

Most RMN partners have a base station and a waterproof shuttle. The couplers (which come with the base station) make both download devices compatible with the various HOBO sensors, meaning the same device can be used for the Pendant, ProV2, DO and U20 series sensors (a photo of the couplers is shown in Figure 7). The waterproof shuttle is used by most field crews because it is easier to work with in the field than the base station (which is not waterproof and requires a laptop with HOBOware software). A downside of the HOBO waterproof shuttle is that you won’t be able to view the data files until after they’ve been transferred from the shuttle to a computer with HOBOware.

Figure 7. The Onset HOBO sensors require a base station and HOBOware software to configure and launch the sensors and to download data. A waterproof shuttle is available for data downloads as well. The couplers (which come with the base station) make both devices compatible with the various HOBO sensors.

5 Field forms

The “Best Practices” document (USEPA 2014) contains several different field forms that you can use or adapt for your specific needs. These include:

- USEPA 2014 - Appendix C. Forms for temperature sensor accuracy checks

- USEPA 2014 - Appendix D. Temperature sensor deployment and tracking forms
- USEPA 2014 - Appendix G. Mid-deployment/maintenance check form.
- USEPA 2014 - Appendix H4. QA/QC checklist form for temperature sensor data

6 Data management

Each RMN partner must act as custodian of their own continuous sensor data. If you do not have a data management system that can accommodate continuous sensor data, EPA and RMN partners have developed tools and training materials to make managing continuous data easier. This includes recommendations on folder and file organizational schemes, as well as free tools to help with QA/QC, summarizing, and visualizing continuous data. The instructional materials can be found on the ContDataQC website - https://nalms.shinyapps.io/ContDataQC/.

ContDataQC is a free, open-source tool, available as either a website/Shiny app (which does not require use of R software) or a R package (https://github.com/leppott/ContDataQC/). ContDataQC can perform many different functions. The QC function runs data through four tests (gross, spike, rate of change and flat line). Values that fail the tests are flagged. Missing entries (which affect metric calculations) are noted as well. After QA/QC is performed, ContDataQC can calculate basic statistics (daily/monthy/seasonal/annual time periods) and generate time series plots. For more information, contact Jen.Stamp@tetratech.com

If you are planning to use ContDataQC, there are specific requirements for formatting and naming files as well as folders. It will save you a lot of time if you use the specified format and naming scheme from the start (vs. having to go back later and change things). Configuration settings are important to keep in mind as well. If you fail to set the air and water temperature sensors to record at the same time, it affects data quality and adds to data processing time. We are learning as we go and are sharing lessons learned along the way, in hopes that new participants will have better tools and a more streamlined, efficient process.

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Attachment 1

List of resources for stream RMN partners

Table A1. List of RMN resources.

Name	Description	Citation	To obtain	Status
Protocols documents	Synopses for each of the recommended parameters, with sections on: rationale for collecting the parameter; three levels of participation: ‘minimum’, ‘target’ and ‘better’; protocols; basic equipment needs, considerations and estimated costs; data recording requirements; data management; and helpful resources.	Stream RMN Protocol Documents - Version 1.1. (1/23/2020) • Temperature • Hydrology • Macroinvertebrates – Northeast • Macroinvertebrates - MidAtlantic • Macroinvertebrates – Southeast • Macroinvertebrates – Upper Midwest (Region 5)	Contact Britta Bierwagen (Bierwagen.Britta@epa.gov). Will eventually be available on the EPA RMN website (www.epa.gov/rmn)	Completed (January 2020); will be updated as needed (and as resources permit)
RMN data analysis plan	Provide examples and guidance on options for preparing and analyzing biological, thermal and hydrologic RMN data so that RMN partners can perform similar types of analyses on their own data.	Stamp, J. 2018. Regional Monitoring Networks (RMN) Data Analysis Plan. Prepared by Tetra Tech for US EPA NCEA/ORD.	Available upon request from Britta Bierwagen (Bierwagen.Britta@epa.gov)	Completed (2018)
GIS-based screening	ArcMap tools developed by EPA that produce watershed delineation shapefiles with watershed properties, such as land cover, size, slope, sinuosity, baseflow, dams and pollutants.	Gibbs, DA; Bierwagen, B. (2017) Procedures for delineating and characterizing watersheds for stream and river monitoring programs. (EPA/600/R-17/448F). Washington, DC: U.S. Environmental Protection Agency, Office of Research and Development.	https://cfpub.epa.gov/ncea/global/recordisplay.cfm?deid=339232	Completed (2017)
RMN report	Describes selection of sites, expectations for data collection, the rationale for collecting these data, data infrastructure, examples of how the RMN data will be used and analyzed	U.S. Environmental Protection Agency (U.S. EPA). 2016. Regional Monitoring Networks (RMNs) to detect changing baselines in freshwater wadeable stream. (EPA/600/R-15/280). Washington, DC: Office of Research and Development, Washington.	Available online: https://cfpub.epa.gov/ncea/global/recordisplay.cfm?deid=307973	Completed (2016)

RMN QAPP	Details the core requirements for participation in the network and outlines best practices for the collection of biological, thermal, hydrologic, physical habitat, and water chemistry data at RMN sites. Was written in a way that should be transferable across regions, with region-specific information included in attachments.	U.S. EPA (United States Environmental Protection Agency). 2016. Generic Quality Assurance Project Plan for monitoring networks to document long-term conditions and detect changes in high quality wadeable streams.	Available upon request from Britta Bierwagen (Bierwagen.Britta@epa.gov)	Completed (2016)
'Best Practices' report	Provides guidance on how to collect accurate, year-round temperature and hydrologic data at ungaged wadeable stream sites. Addresses questions related to equipment needs, sensor configuration, sensor placement, installation techniques, data retrieval, and data processing	U.S. Environmental Protection Agency (U.S. EPA). 2014. Best Practices for Continuous Monitoring of Temperature and Flow in Wadeable Streams (Final Report). U.S. Environmental Protection Agency, Office of Research and Development, National Center for Environmental Assessment, Washington, DC, EPA/600/R-13/170F	Available online: https://cfpub.epa.gov/si/si_public_record_report.cfm?dirEntryId=280013	Completed (2014)
Pilot study report	Pilot studies in which state macroinvertebrate datasets in Maine, North Carolina, Utah and Ohio were mined for climate-related trends	U.S. Environmental Protection Agency (U.S. EPA). 2012. Implications of Climate Change for Bioassessment Programs and Approaches to Account for Effects. Global Change Research Program, National Center for Environmental Assessment, Washington, DC; EPA/600/R-11/036F	Available online: https://cfpub.epa.gov/ncea/global/recordisplay.cfm?deid=239585	Completed (2012)