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

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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 hydrologic measurements, divided into three levels of participation: ‘minimum’, ‘target’ and ‘better’. At a minimum, water level measurements should be taken seasonally at 30-minute intervals. If resources permit, participants are encouraged to collect data at the ‘target’ or ‘better’ 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 collecting water level data year-round[1] at 15-minute intervals (in keeping with typical USGS gage recording intervals), installing a staff gauge and/or establishing a reference mark, performing elevation surveys, developing a flow-rating curve to allow for conversion of water level data to discharge, and monitoring for changes in the water level-discharge-channel relationship over time (and making corrections to account for these changes as needed). The highest level of participation calls for deploying a precipitation gauge and time lapse camera as well. Photos and water level sensor data can now be uploaded to the Flow Photo Explorer (https://www.usgs.gov/apps/ecosheds/fpe/#/). It is free and accessible to the public. The computer artificial intelligence (AI) component to Flow Photo Explorer is currently being developed to train computers to interpret water level from the stream images. For more information, visit the Flow Photo Explorer website and/or contact your EPA RMN regional lead.

[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. Additionally, winter gaging requires additional effort to track and correct for the variable impacts of ice on water levels, for which time and resources may not be available.

Table 1. Hydrologic measurements are divided into three levels of participation: 'minimum', 'target' and 'better. Participants are encouraged to collect data at the 'target' or 'better' 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.

<table>
<tr><th rowspan="2">Component</th><th colspan="3">Level of participation</th></tr>
<tr><th>Minimum</th><th>Target</th><th>Better</th></tr>
<tr><td>Type of data</td><td>Water level only</td><td>Water level and discharge</td><td>Water level, discharge, time-lapse photos[1] and precipitation[2]</td></tr>
<tr><td>Recording interval</td><td>every 30 minutes</td><td colspan="2">every 15 minutes</td></tr>
<tr><td>Deployment period</td><td>Seasonal
(e.g., summer only)</td><td colspan="2">Year-round</td></tr>
<tr><td>Elevation survey</td><td>Performed annually</td><td colspan="2">Performed more than once a year, as needed (e.g., if a storm moves the sensor and it must be redeployed)</td></tr>
</table>

[1]A project is currently underway in which time lapse cameras are being deployed with water level sensors (USGS gages or pressure transducers), and computers are being trained (artificial intelligence (AI)) to estimate water level (and possibly discharge) from the photos. If you are interested in learning more about this project and would like to obtain the protocols for deploying the cameras, contact Britta Bierwagen (Bierwagen.Britta@epa.gov).

[2]If you have limited resources and need to choose between a precipitation gage vs. taking discharge measurements, discharge measurements are higher priority.

2 Protocols

There are a number of ways to measure water level. In this document, we focus on vented and nonvented pressure transducers because most RMN partners are using them at sites that aren't co-located with USGS gages. With non-vented pressure transducers, you need an on-land sensor to measure barometric pressure to account for changes in atmospheric pressure (which changes with weather and altitude) in weather and altitude. Failure to account for these variations will result in erroneous water level measurements.

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. Anytime you deploy a sensor, there is a risk of the sensor being lost or damaged. The RMN protocols include measures to help minimize these risks and are based on designs that have been tested and successfully used by various entities for multiple years. These designs can be adapted/customized for your own sites as needed.

If you deploy water level 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)

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

2.1 Pre-deployment preparations

Pre-deployment preparations involve the following steps:

- Site reconnaissance
- Sensor accuracy check
- Sensor configuration and launch

2.1.1 Site reconnaissance

We recommend performing site reconnaissance in advance of deploying the sensors. Photos in particular are very helpful. 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?
    - Is it likely that the floodplain will be accessed?
    - Can the location be safely accessed and waded by crew members year-round? If not, when is the location likely to be inaccessible?
- Is there a downstream feature that controls water levels where you're considering putting the sensor (to allow for stable water level measurements and ensure that the sensor will be submerged during low flows)? Such "section controls" are preferable. Examples include riffles or culverts that are narrower than the stream channel and constrict flow; for more information, see Section 3.2.1.1).
- Is there a suitable place to take discharge measurements? (see Section 3.8.3 in the "Best Practices" document; USEPA 2014)
- 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? Changing channel cross-sections complicate stage-discharge relationships and may also result in burial of loggers.
- What level of human activity occurs at the site? How big a concern is vandalism?
- What types of flow habitats occur in the reach? (runs and pools are preferred installation sites over riffles).
- 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
    - extensive aquatic vegetation

- point-source discharges
- streamside wetland areas
- hot springs
- groundwater seeps

2.1.2 Sensor accuracy check

The transducers that most people are using are factory calibrated prior to being shipped. Some RMN partners are also doing pre-deployment accuracy checks in the lab/office. A simple ‘bucket’ technique involves: 1) programming the sensors to record at short intervals (e.g., every minute) with a second open-air logger for barometric compensation if needed; 2) putting the water level loggers into a 5-gallon bucket that contains water of a known depth and leaving them in long enough to get several measurements; 3) emptying a few inches of water out of the bucket and re-measuring depth; 4) get a few more readings; and 5) calculating the difference between the two depths and comparing them to the sensor readings (the difference should be within the accuracy range of the sensor). If you perform a check like this, you can also verify that the sensor is launching and downloading data properly and that the sensor has sufficient battery life. In addition, you can also check the accuracy of the temperature sensor (which is part of the pressure transducer; for instructions, see Section 2.2.1 in the “Best Practices” document (USEPA 2014)). For more information, contact Britta Bierwagen (Bierwagen.Britta@epa.gov).

2.1.3 Sensor launch and configuration

Water level sensors are configured to record measurements at 15-minute intervals (in keeping with typical USGS gage recording intervals). 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), and quarter hour (xx:15 or xx:45)
- Record in consistent units (for water level, feet; temperature, °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. However, this does not allow you to associate a manual reference water level measurement with a sensor logged value, potentially making QA/QC procedures more difficult. 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: Avoiding out-of-sync air and water sensors

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 process.

2.2 Initial deployment

Initial deployment involves the following steps:

- Install the sensor
- Perform elevation survey
- Take reference water level measurement
- Document the site
- Perform discharge measurements
- Take another reference water level measurement

2.2.1 In-water sensor

2.2.1.1 Placement

The transducer should be installed in a pool where turbulence is minimal to increase accuracy of transducer and (if applicable) gauge readings. The pool should have a downstream control feature that allows for stable measurements of stage and the stage-discharge relationship, and ensures that the sensor will be submerged during low flows. Natural controls might include a downstream riffle, bedrock outcrop, or other stream feature that controls water level at a given flow (Figure 1A). Unnatural controls might include a bridge or culvert that is narrower than the stream channel and constricts flow (Figure 1B). Note that the feature controlling the stage-discharge relationship can change at different flow levels; such changes will be reflected in the stage-discharge rating curve.

If possible, the water level sensor should be close to where the biological data are being collected. For our purposes, however, the water level data just need to be representative of the larger reach (the location of the sensor and biological sampling locations do not need to overlap exactly).

Ensure that the water level sensor 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 site should not have extensive aquatic vegetation, beaver activity, or unstable streambeds and banks. These factors can change or result in unstable stage-discharge relationships.

More detailed information on site selection and controls can be found in Rantz et al. (1982).

Figure 1. Examples of controls downstream of staff gages include A. riffle and B. culvert.

2.2.1.2 Installation

Techniques for deploying the pressure transducers vary depending on many factors. Site-specific conditions will dictate which installation technique is most appropriate. Here we briefly describe two installation methods:

- the fixed object method
- the streambed method

With the fixed object installation, the pressure transducer is attached to a staff gage board or to an object like a bridge or boulder (Figure 2). A staff gage board can be secured to a post driven into the streambed or anchored directly to a bedrock or concrete surface. With the streambed installation, the transducer is affixed to and held in place by stable rock on the streambed or rebar driven securely into the streambed (Figure 3). Compared to the fixed object method, transducers are more prone to moving or being swept away during high flows. It is also more difficult to ensure that transducers are returned to the same location[2] after being removed for data downloads. Access to loggers near the streambed can also be made more difficult during higher water levels. In both cases, sensors should be enclosed in some type of protective housing. The "Best Practices" document (USEPA 2014) contains instructions and equipment lists for doing either type of installation.

Figure 2. Examples of fixed object installations in which non-vented (left) and vented (right) pressure transducers are attached to a staff gage board using conduit hangars.

[2]For streambed installations, we are seeking ideas on better ways to affix the sensor in a reproducible position; please send ideas to Britta Bierwagen (Bierwagen.Britta@epa.gov) and we'll add them into the next version of this document.

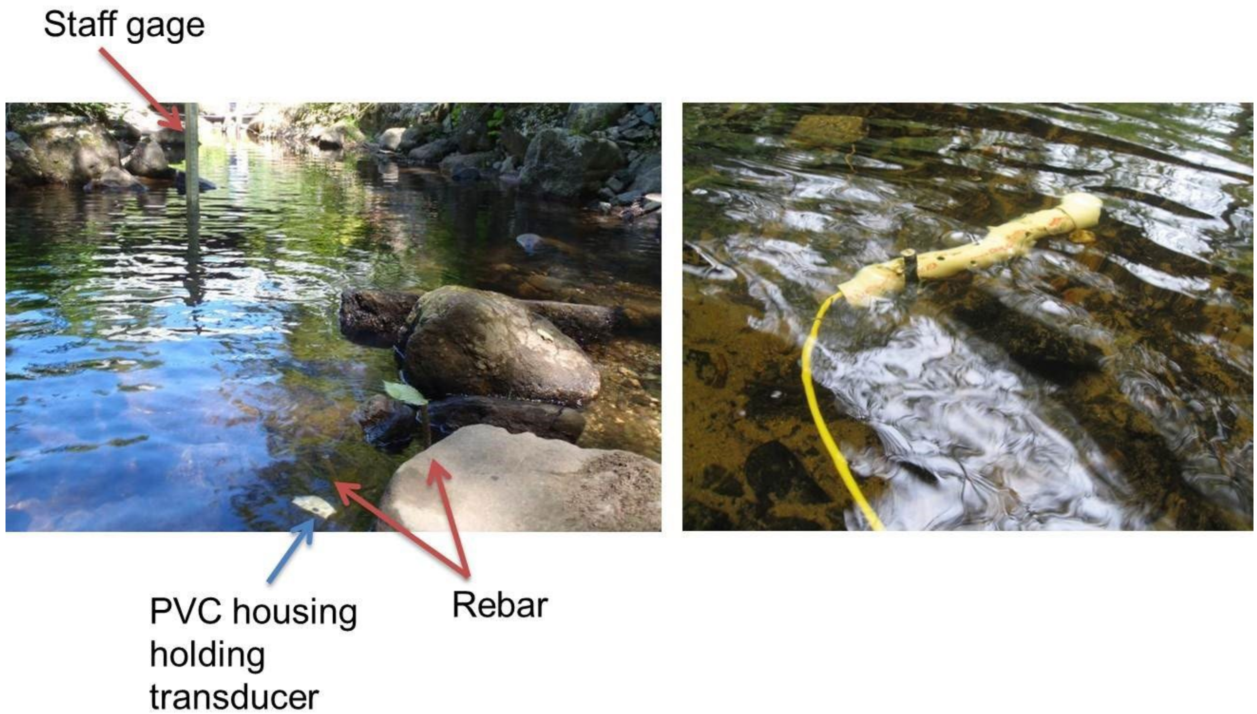

Figure 3. Examples of streambed installations of pressure transducers using rebar.

2.2.2 On-land sensor

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, two transducers are deployed – one on land and one in the water. The one on land is used to measure and account for barometric pressure from the atmosphere that is measured by the submerged sensor in addition to pressure due to depth of water[3].

Both types of sensors should be -

- Placed in suitable areas that are near the in-water sensors and biological sampling area
- Kept in the same location over time (and if a sensor needs to be moved, this must be documented in the field notes)
- Encased in a protective housing/radiation shield (see Section 5.2).
- Placed in areas that are located well above where high flows or the snow pack will reach, but not so high that they are inaccessible for data downloads
- Hidden from view to the extent possible to reduce the chance of vandalism

[3]Because atmospheric pressure changes with weather and altitude, compensating for barometric variations is necessary; failure to account for these variations will result in erroneous water level measurements. If you're using non-vented pressure transducers, we encourage you to purchase and install an on-land sensor to measure barometric pressure, although in some situations, data from a nearby weather station may be sufficient. Whichever data source is used, it is critical that the barometric pressure readings accurately represent on-site conditions

Trees are generally the most suitable attachment points. Vegetation creates radiation microenvironments so try to minimize the amount of other vegetation near the sensor. If suitable trees are not available, attach the sensor to an existing or constructed stable structure (e.g., fence post).

Non-vented transducers. The non-vented transducers measure temperature as well as pressure, and air temperature is one of the target parameters for RMNs. To collect air temperature in keeping with typical meteorological observations, the on-land transducer is placed at a height of 2 meters, or approximately 6 feet, off the ground. It is important to keep the on-land transducer out of direct sunlight if possible (when installing it, try to mount it on the north-facing side of the structure). Figure 4 shows an example of a typical installation. The sensor is housed in a PVC shield with holes drilled into the sides and bottom. The holes in the bottom prevent condensation and laterally blown rain and snow from filling the cup to a depth sufficient to inundate the port through which the barometric pressure is compensated. If this occurs, the “barometric pressure” becomes barometric pressure plus a small amount of pressure due to this accumulated water, and the data cannot be used. This issue can also be addressed by deploying the barometric pressure sensor upside down, so that the port is on top.

Note: some RMN partners have had problems with spiders nesting in the sensor port hole, which affects the barometric pressure readings. To prevent this, some people have glued fiberglass screen inside the PVC housing (or purchased PVC housing that comes with a screen).

Figure 4. Barometric pressure sensor installation for a non-vented transducer. Holes should be drilled into the bottom cup of the PVC housing. This prevents condensation and laterally blown rain and snow from filling the cup to a depth sufficient to inundate the port through which the barometric pressure is compensated. Another option is to deploy the barometric pressure sensor upside down, so that the port is on top.

Vented transducers. Unlike the non-vented transducer, vented transducers have a cable that connects the in-water and on-land device (which we refer to as a data logger). The vent tube automatically offsets atmospheric pressure so the pressure sensor only measures that of the water above it. This requires additional deployment considerations plus measures to keep the vent tube free of any moisture.

The data logger is typically housed in a pipe that is attached to a fixed object on the bank (see example in Figure 5). People generally use a PVC (Figure 5) or stainless steel (Figure 2) pipe. Put a cap on top of the pipe to protect the equipment and discourage vandalism. Install the data logger is in a way that doesn't put pressure on the vented cable. This can be done by resting it on the bottom of the pipe or by suspending it from a wire or cable. If you hang it from a wire, leave enough slack to allow the device to be lifted out of the pipe to download data. Hide the vented cable that connects the in-water transducer with the data logger to the best of your ability (if there is excess cable, coil the cable and zip tie it to pipe, tree or other structure; where the cable runs along the ground, use things like garden staples, leaf litter or rocks to secure and cover it, but be careful not to pinch the cable).

Figure 5. Vented transducer on-land data logger installation. The transducer is attached to the tree with stainless steel conduit straps

For more details on vented and non-vented transducer installations, see the "Best Practices" document (USEPA 2014).

2.2.3 Elevation Survey

It is important to survey the elevation of the pressure transducer and (if applicable) staff gauge to establish a reference point. 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.

Before performing elevation surveys, you need to establish permanent reference marks[4], which are referenced when checking elevations. Reference marks should be very stable and permanent (e.g., a mark on a bridge, an 'X' etched into concrete, a bolt drilled into a structure) to ensure consistent measurements from one year to the next. We recommend setting up more than one reference marker some distance from the first so that you have a back-up if something happens to the primary marker (e.g., it becomes dislodged due to frost heave or tampering).

Step by step instructions on how to conduct elevation surveys can be found in Section 3.5 of the "Best Practices" document (USEPA 2014). Additional information on surveying techniques can be found in Harrelson et al. 1994 and WI DNR (2015).

An elevation survey should be performed on the day of the transducer installation. After that, conduct elevation surveys at least once a year to identify if and when movement occurs. This is particularly important after high flow events and periods of extended ice cover. Figure 6 shows equipment that is typically used when performing elevation surveys (an auto level, tripod and stadia rod). If you don't have the equipment and/or expertise to perform elevation surveys, we encourage you to look for other organizations to partner with who are able to perform the surveys.

Figure 6. Examples of auto level and tripod used for elevation survey (A) and permanent structure used as a benchmark (B).

2.2.4 Discrete (instantaneous) reference level measurement

[4]If the elevation of the reference mark is established, it is called a benchmark.

It is important to measure water level in relation to a permanent reference mark (referred to as a 'reference water level measurement') during each site visit if possible. These measurements provide a quality check of transducer data (Figure 7). They enable you to relate the sensor water level measurements to a fixed, meaningful reference point (such as a surveyed staff gauge (Figure 8) or other permanent benchmark, such as a bridge beam(Figure 9)) and allow you to check for sensor drift over time.

Reference water level measurements from surveyed staff gauges are encouraged when possible. Instructions on how to install staff gauges can be found in Section 3.3.2 in the "Best Practices" document (USEPA 2014). If you don't have a staff gauge, take the reading in relation to a permanent reference mark. There are many potential ways to do this. Examples include - -

- Use a stable structure on the bottom of the stream, such a boulder, and measure up to water surface. Make sure to mark this spot so that you can measure from this same spot for future water level reference measurements.
- If there aren't boulders, you could drive a PVC pipe or rebar into the bottom and use that instead.
- Reference a mark on a vertical structure, such as a boulder along the stream or a bridge support, and measure from this mark vertically down to the water surface (Figure 9). This mark can be natural, painted, or a plate, bolt, or screw affixed to the object.

To improve the accuracy of your water level measurements, if water levels are fluctuating, take several readings and record the average. Also, make sure your stadia rod or ruler (or whatever device you are using) is plum and level (some people use hand-held eye levels, drywall T-squares or torpedo levels…there are many possibilities).

If for some reason you need to start using a new reference marker part-way through the deployment, a new water level data set should be created using this new reference mark as the standard. The use of a new reference mark should be clearly noted in your field notebook. Water levels using different reference markers may not be comparable if the markers are located at different elevations above the land-water interface. Careful elevation surveying relating an old and new marker would allow for adjustment and correction of past water level data.

If you are unable to take reference water level measurements, at a minimum, try to measure sensor depth (from the water surface to sensor diaphragm). Compare this measurement to the sensor reading (it should be close). If the in-water sensor is hanging from a cable in a stilling well, it can be difficult to get an accurate measurement. A technique that some RMN partners have had success with is to note where the water line is on the cable when you pull up the sensor, and measure from that point to the sensor diaphragm.

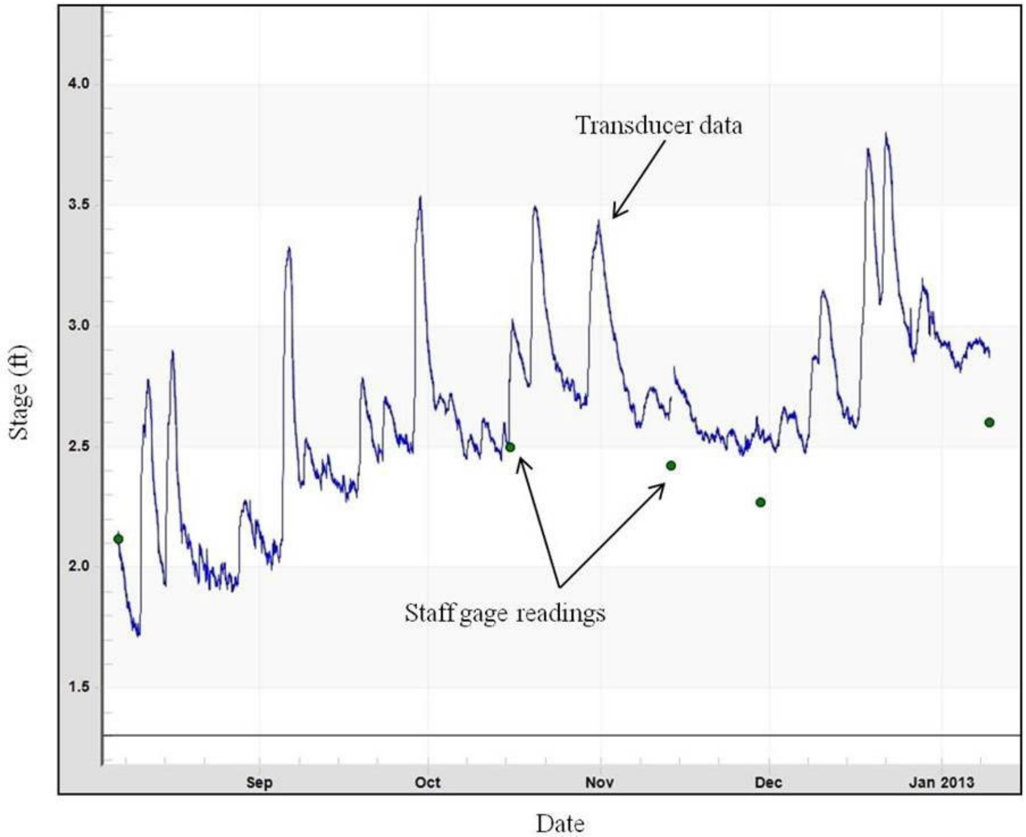

Figure 7. Staff gage readings provide a quality check of transducer data. In this example, staff gage readings stopped matching transducer readings in November, indicating that the transducer or gage could have changed elevation or suffered from sensor drift.


Figure 8. Example of a USGS style staff gage (Type A) marked in 0.02-foot increments.

Figure 9. Example of a reference water level measurement taken from the surface of the water to the top of a bridge beam.

2.2.5 Documentation

It is critical to document the location of the sensors and benchmarks to the best of your ability so that you (or others) can relocate the sensors after initial 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 sensor. Archive photos in a central database for future use.
- Make detailed hand-drawn maps with landmark references (e.g., unique rock, log, root, flagging, or tree), sensor locations, direction of stream flow, places to park, paths to the stream, and any other characteristics that might be appropriate, annotate photographs when viewing them later.
- 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 with your organization name and contact information in case it is located by outside entities. If your organization has specific policies regarding signage, follow those protocols.

2.2.6 Discharge measurements

Discharge (streamflow) measurements are optional but encouraged. They are used to develop stage (water level) - discharge rating curves, which allow the user to convert water level measurements to discharge (to quantify volume over time). To develop a rating curve, a series of discharge measurements are made at a variety of water levels. This involves measuring the depth and velocity of the water passing through several segments along a given cross-section of stream (Figure 10). Each measured velocity is multiplied by its contributing flow area; the resulting flows are summed across the cross-section to produce a total flow.

To establish a rating curve, take five to ten sets of discharge measurements across as wide a range of flows as possible, noting the reference water level both before and after each measurement. The stage-discharge data points are then plotted and an equation derived to describe their relationship across a range of flows. It is this equation that is used to estimate streamflow from your continuous time series of water level. Note that if this equation will be derived automatically via a computer program, the chart tools in some common spreadsheet software programs such as MS Excel do not necessarily produce a best fit equation the minimizes the sum of squared errors, and therefore result in a rating curve whose r-squared value is not optimized. Regression model parameters can be optimized using measured discharges vs. rated discharge with Excel's Solver add-in to minimize the sum of squared errors, or alternative statistical software that achieves this may be used for this process (for more information on this approach, contact Blaine Hastings from VT DEC (Blaine.Hastings@vermont.gov).

After establishing a rating curve, measure discharge at least once annually, and if possible, also after large storms or any other potentially channel-disturbing activities, to verify or (if needed) update the curve.

Instructions on how to take discharge measurements can be found in Section 3.8 of the "Best Practices" document (USEPA 2014), as well as from Rantz et al. (1982), Chase (2005), or Shedd (2011).

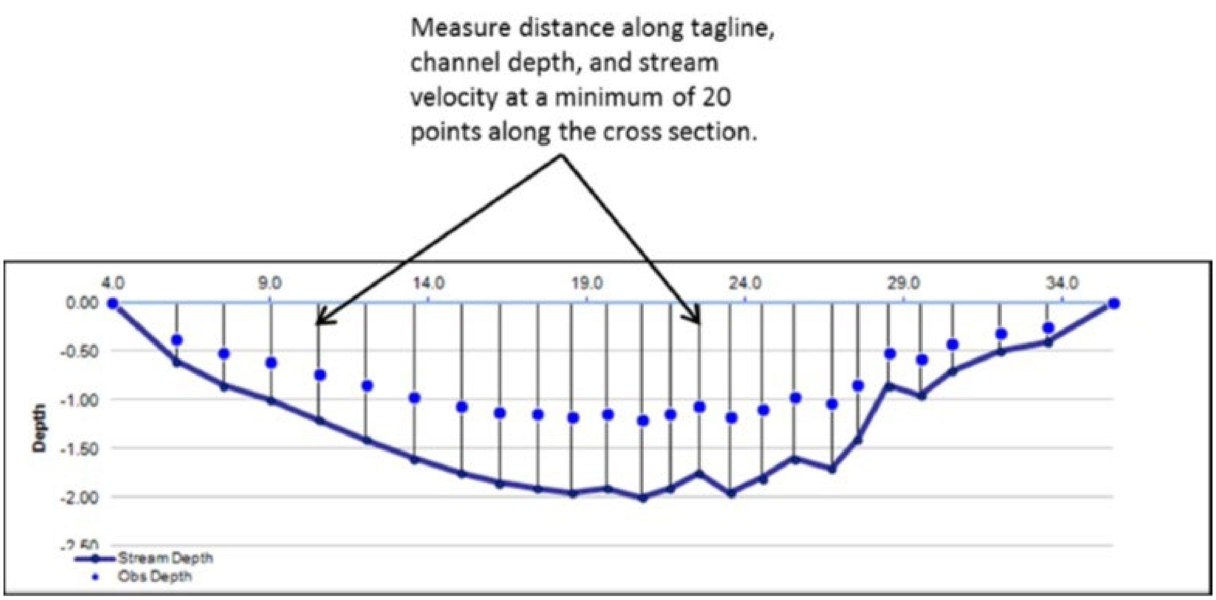

Figure 10. Layout of a channel cross-section for obtaining discharge data, using the velocity-area procedure.

2.3 Follow-up visits

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

If possible, download data during each site visit. Frequent data downloads, as well as frequent reference water level measurements, will help in early identification of sensor movement or drift.

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

- Prepare equipment
- Locate the sensors
- Take reference level measurement
- Sensor download and maintenance activities
- Perform elevation surveys at least once a year
- Perform discharge measurements (optional but encouraged)
- If you take discharge measurements, take another reference water level measurement after taking the discharge measurements

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 and laptop or waterproof shuttle – see Section 5.3) is up to date. 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.

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).

In some cases, RMN partners have used metal detectors to help find their sensors.

2.3.3 Discrete (instantaneous) reference level measurements

Before you remove the in-water sensor to download data, take a discrete/instantaneous reference water level measurement (see Section 3.2.2), as close as possible to the sensor and as close as possible to the time when the sensor is recording a measurement. For the best accuracy, take multiple reference water level measurements and average them. Some RMN partners also take a measurement after the sensor is redeployed (after download) as an additional QC check. Record the reference water level measurement on a field form.

2.3.4 Sensor download and maintenance activities

When you retrieve the sensors to download data, be sure to write down the time the sensors are moved from their normal position (this is important to know for data QA/QC). To download data, follow the sensor manufacturer's instructions and use the appropriate device(s). Once the data download is complete, return the sensors to the same location as before.

If you are using Onset HOBO sensors, instructional materials on downloading data can be requested from Britta Bierwagen (Bierwagen.Britta@epa.gov). 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). 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. For more information, see Section 5.3.

During site visits, perform the following checks –

- Ensuring that the instream pressure transducer is *submerged and not buried in sediment.*
- *Clearing leaf litter and debris* that might pile up against the transducer, gauge and downstream control. At the beginning of a site visit, clear this material as it could impact water level. Note the water level before and after debris clearing in your field notes. Wait to take additional measurements until water levels have stabilized. Water level data may be corrected if changes are detected.
- *Checking for transducer and staff gauge movement after high flows and floods*. The difference in elevation between the transducer and staff gauge (or other reference mark) can change if sediment accumulation or scour occur near the transducer and gauge. If movement is detected, secure the equipment (if necessary) and resurvey. Note any differences in transducer and reference mark elevation in a field notebook along with the date and time. If equipment is constantly shifting, consider an alternative location.
- *Checking for impacts from ice cover*. Data should be evaluated for potential impacts from ice cover and data should be flagged accordingly.
- *Cleaning sediment or algae from the pressure transducers.* These can cause fouling and inaccurate readings. Consult the transducer manual for specific instructions on cleaning and maintenance.
- *(if applicable) Cleaning the staff gauge* with a scrub brush, especially during the summer months, so that the gage can be accurately read. For especially dirty gages, baking soda or

native sand (if available in situ) can help in cleaning the gage. Paint over any rust marks on the gage with enamel paint to improve durability.

- *Checking the condition of desiccant packets* (vented transducers only). These are needed to keep the vented cable dry. Different transducers use different types of packets, and the lifespan of these packets varies depending on site-specific conditions (e.g., how much moisture is present in the air).
- *Check battery life*. Batteries in some sensors need to be replaced each year, while others last 5 years or longer under normal use. Plan for replacements as needed.
- *(if applicable) Compare measured discharge to rated discharge expected based on water level*. If there is a notable difference, check for explanations for variance in downstream channel or control, such as scour, deposition, vegetation, or ice impacts. Consider repeating discharge measurement if inaccurate initial discharge measurement is suspected.

Record information from mid-deployment checks in a field notebook or on a field form. Taking good field notes during every site visit is essential. Entries should include notes about the condition of the transducer, staff gage (or other water level) readings, and whether any unusual measurements appeared during the data spot-check (if available). Tip: take a photo of your field notes before leaving the site as an additional form of backup should something happen to your notebook.

Taking photos during each site visit is also good practice, as this will help document changes to the monitoring location during the course of the deployment. If you see anything that could affect the accuracy of the measurements, make a note about it on the field form.

2.3.5 Elevation surveys

Conduct elevation surveys at least once a year (ideally more) to identify if and when transducer or staff gauge movement occurs. This is particularly important after high flow events and periods of extended ice cover. Instructions on how to perform elevation surveys can be found in the “Best Practices” document (USEPA 2014). If you don’t have the equipment or expertise to perform the surveys, explore partnerships with organizations who have this capability.

2.3.6 Discharge measurements

Discharge measurements to establish flow-rating curves are optional but encouraged. They should be taken across as wide a range of streamflow as possible. Instructions on how to take discharge measurements can be found in the “Best Practices” document (USEPA 2014), as well as Rantz et al. (1982), Chase (2005), or Shedd (2011).

Getting high flow measurements can be challenging. Some RMN partners are using crest-stage gages to get maximum water level measurements during storms and floods (Figure 11). A wooden board with water level markings is housed inside a steel pipe. Holes are drilled into the bottom of the pipe, which allows water to enter. Then ground cork is placed in the bottom of the pipe. When it rains, the water in the pipe rises, which floats the cork in the pipe. When the water stops rising, then falls, the cork sticks to the wooden rod at the highest point where the water was. During each site visit, field crews measure the height of the cork line, then clean the cork off the wooden board and replenish the cork.

Obtaining discharge measurements during high flow events can obviously be challenging as well. Protocols for a float method that could potentially be used during non-wadeable flow is available upon request (contact Britta Bierwagen (Bierwagen.Britta@epa.gov)).

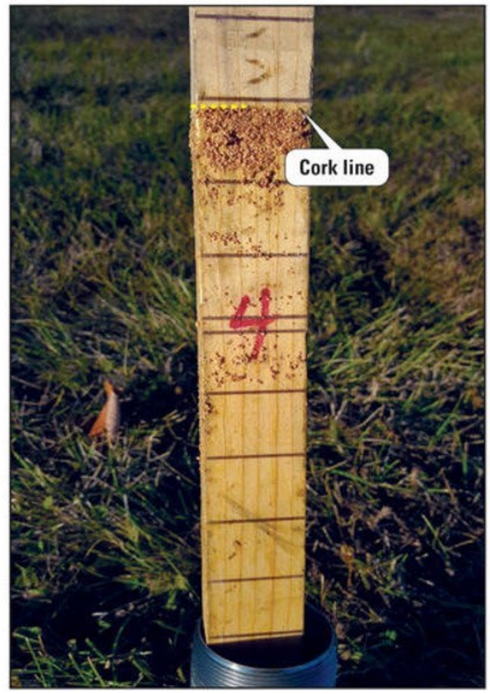

Figure 11. Some RMN partners are using crest-stage gages to get maximum water level measurements during storms and floods. A wooden board with water level markings is housed inside a stainless steel pipe that has holes in the bottom. When it rains, the water in the pipe rises, and floats cork that is placed at the bottom of the pipe. When the water stops rising, then falls, the cork sticks to the wooden board at the highest point where the water was.

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 water level measurements with pressure transducers 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)
- (if applicable) Ensure the Onset HOBOware software updates are being performed (as needed) on laptop and/or waterproof shuttle before going into the field

- Annual accuracy tests and calibration, if possible
- Track problems and needs

Field visits

- Make sure reference water level measurements are being taken
- 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
- Take discharge measurement if possible

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 in 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
- After each download, make sure a standard set of procedures are performed to ensure the quality of the data and make necessary corrections. 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.

Accuracy checks

The pre-deployment accuracy check described in Section 3.1.2 (the lab or office 'bucket' test, or something comparable) is encouraged, but optional. After the sensor data are downloaded and viewed on a computer, the discrete reference water level measurements (Section 3.2.3) are matched with the closest sensor measurements and differences are evaluated. In the example shown in Figure 7, the reference level measurement (in this case, a staff gage reading) stopped matching transducer readings at a certain point in a way that indicated that the transducer or gauge likely changed elevation. Checks like this make the data more defensible and can potentially be used to make corrections. They should be performed sooner rather 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).

Evaluating differences between discrete manually measured reference water level vs closest matching sensor measurements (adjusted to the gage's datum) can also be used to detect sensor drift. This should be done during periods of calm and relatively stable water levels. If you are using Onset HOBO U20 sensors, guidance on how to check for sensor drift while processing data in HOBOware is available upon request from Britta Bierwagen (Bierwagen.Britta@epa.gov).

Data screening checklists

A data screening checklist can be found in Table 2 as well as Appendix K in the "Best Practices" document (USEPA 2014). Specific errors to watch for include: missing data; values of 0 (which could mean that the pressure transducer was dewatered, or in the case of vented transducers, could mean that moisture entered the cable); values flat-lining at 0°C/32°F (the stream pressure transducer is likely encased in ice); negative values (if unvented transducers are being used, this could indicate that the barometric pressure correction is off); unusual diurnal patterns in the data (one person had this occur when a spider nested in the sensor port of the on-land pressure transducer, which threw off the barometric pressure readings); and outliers or rapidly fluctuating values (the stream pressure transducer could have moved (e.g., due to a high flow event or vandalism). Various software applications can be used to help with the error screening checks (e.g., Microsoft Excel, Aquatic Informatics' AQUARIUS (http://aquaticinformatics.com/products), including software that is purchased with the transducers(s)).

Table 2. General summary of different types of problems that can occur with pressure transducer data and recommended actions for addressing them.

Problem	**Recommended action**
Missing data	Leave blank
Stream pressure transducer was dewatered or buried in sediment for part of the deployment period	Use the plot (and temperature data, if available) to determine the period during which the problem occurred. Exclude these data when calculating summary statistics.
Recorded values are off by a constant, known amount (e.g., due to a calibration error)	Adjust each recorded value by a single, constant value within the correction period.
Drift is large and when and how much the sensor was 'off' cannot be determined (when drift occurs, the difference between staff gage or depth readings and pressure transducer readings increases over time)	The data should be removed.
Discrepancy between pressure transducer reading and discrete manual reference water level measurement taken during a staff gage or depth check	General rules: • If the errors are smaller than the accuracy quoted by the manufacturer and cannot be easily corrected (e.g., they are not off by a constant amount), leave the data as is, and include the data in summary statistics calculations. • If the transducer fails a staff gage or depth accuracy check, review field notes to see if any signs of disturbance or fouling were noted, and also look for notes about the quality of the gage measurement (Were flows fluctuating rapidly at the time of the measurement?). Also check whether the same time setting was used for both the transducer and gage or depth measurements (daylight savings time vs. standard time). Based on this information, use your best judgment to decide which action (leave as is, apply correction, or remove) is most appropriate.

A shift is detected and an elevation survey reveals that the stream pressure transducer has moved	Stage readings can be adjusted by adding or subtracting the difference in elevation. If the exact date of the elevation change is unknown, compare gage data to transducer data to observe any shifts. If no gage data for the time period are available, transducer data should be examined for any sudden shifts in stage. Changes in the elevation typically occur during high flows, so closely examine all data during these time periods.
The sensitivity of the pressure transducer changes with stage (e.g., the transducer is less sensitive or accurate at high stages)	Sensitivity drift can be detected by graphing the difference between transducer and staff gage readings against the gage height and plotting a linear trend line through it. A strong correlation between the data sets and a positive or negative trend line as stage increases or decreases could indicate a sensitivity shift. Based on this information, use your best judgment to decide which action (leave as is, apply correction, or remove) is most appropriate.

<u>Elevation surveys</u>
Elevation surveys in combination with the reference water level measurements are used to detect physical movement of the sensors, and to make corrections when possible. When performing the elevation surveys, compare the beginning and end Height of Instrument (H.I.) to ensure that there is no movement of the auto level during the survey. In addition, compare elevations of all survey points to previously surveyed elevations to determine if any changes have occurred. For more information, see Section 3.5 in the "Best Practices" document (USEPA 2014).

<u>Discharge</u>
If you perform discharge measurements, the following QC checks are recommended -

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

Good resources for discharge QA/QC include Section 3.8 of USEPA (2014), Rantz et al. (1972), Chase (2005), and Shedd (2011).

4 Equipment

Many different types of sensors can provide continuous monitoring and logging of water level in streams. In this document, we focus on pressure transducers because most entities are using these at RMN sites. In this Section, we provide an overview of equipment needs for:

- Sensors (pressure transducers)
- Radiation shield/protective housing
- Sensor accessories
- Staff gauge
- Elevation surveys
- Discharge measurements

Equipment lists for installing the sensors are not included here but can be found in the “Best Practices” document (USEPA 2014).

When we discuss the various types and brands of equipment, it should not be constituted as an endorsement or recommendation for their use; rather it is for descriptive purposes only.

4.1 Sensors

Pressure transducers are of two main types: vented and non-vented pressure transducers. Vented transducers 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. Non-vented pressure transducers are not connected by cables and do not automatically correct data for barometric pressure. Each have pros and cons, which are discussed in the Best Practices document (USEPA 2014).

Transducers at RMN sites should meet the following specifications:

- **Accuracy of ≤ 0.015 ft**. Accuracy is a function of the operational range of the pressure transducer. As the range increases, the accuracy decreases. Manufacturers specify a full-scale accuracy for a given transducer; multiply this by the expected range of depths to be experienced by the transducer to assess whether the equipment will provide an appropriate level of accuracy. For example, a transducer with a full scale accuracy of ±0.1% should not be used over a range of depths greater than 15 feet.
- **Range to encompass the maximum expected range of stream stages for that location**. A site visit prior to purchasing the transducer will help determine the expected range of flows. Because accuracy decreases as range increases, choose the smallest possible range. A depth range of less than 15 feet should be suitable at most RMN sites.
- **Sufficient cable length to meet installation requirements** (vented transducers only). Some transducers come with a standard 25-foot cable while others must be specified. A site visit prior to purchase will determine the length needed. If a site visit is not possible, a 50-foot cable is typically sufficient.
- **Sufficient battery and storage capacity** to operate at the desired logging interval and site visit frequencies of your program

Most RMN partners are currently using the Onset HOBO U-20 series non-vented pressure transducers (shown in Figure 11A). There are two series: U20 and U20L. Both series are available in 4 water depth ranges: 0 to 13 ft; 0 to 30 ft; 0 to 100 ft and 0 to 250 ft. Select the smallest depth range that is sufficient for the expected variation in water level at each site (as you get into the larger depth ranges, you lose accuracy (in the U20 (silver), typical error is ± 0.05%; in the U20L (black), typical error is ± 0.1%; as an

example, if you have a 0 to 30 ft U20L sensor, the accuracy of the U20L at 30 ft = 0.3 ft). RMN partners generally use the (more accurate) U20 series transducer for the in-water sensor and the U20L transducer on-land[5] (since it doesn't require the same level of accuracy). The U20 series transducer costs $555 and the U20L series transducer costs $330 (as of December 2022), so to equip one site with non-vented pressure transducers, it costs approximately $900. The U20 series sensors typically last about 5 years when set to record at 15 or 30-minute intervals year-round. They both have a temperature accuracy of ±0.5°C. They are durable and can withstand being frozen into the ice.
The vented transducers shown in Figure 12 are generally in the $1300-$1500 range. For more information on the sensors in Figure 12, see Table 15 in USEPA (2014).

Note: some RMN partners have started using the Onset MX2001 Bluetooth Water Level Logger, which is non-vented but has an integrated barometric pressure sensor that enables direct water level readouts (which saves you some processing steps in HOBOware). The barometer and in-water sensor are connected by a cable, and the barometer needs to be above water (like vented transducers) (Figure 12). The MX2011 costs $675 (as of December 2022). Kinks and pronounced bends in the cable may develop after prolonged storage, so care should be taken if the sensor is suspended by the connecting cable. Weights may be used to straighten, or other measures employed to ensure the cable does not stretch and elongate after reference water levels have been taken. We'll add in additional information about this device after RMN partners gain more experience with it.

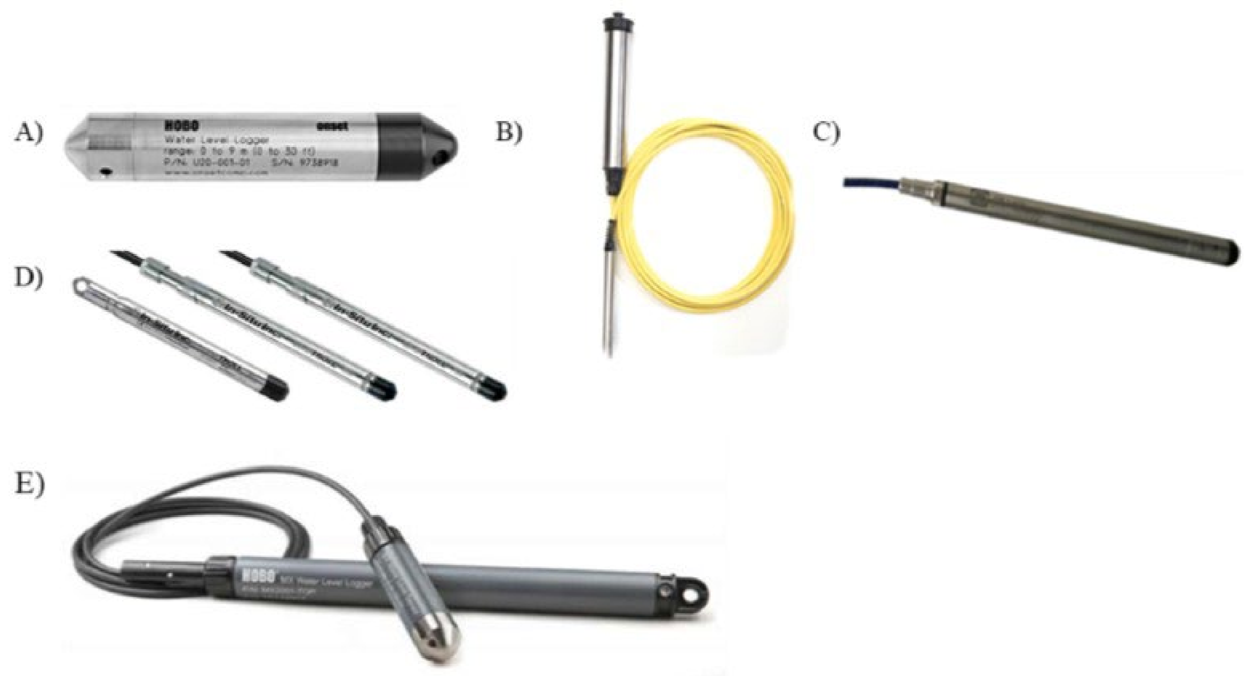

Figure 12. Numerous pressure transducers are commercially available. Some examples include: A) Onset Hobo© U20 series Water Level Data Logger (non-vented); B) Global Waters Water level logger (WL16)

[5] If you're using non-vented pressure transducers, we encourage you to purchase and install an on-land sensor to measure barometric pressure, although in some situations, data from a nearby weather station may be sufficient. Whichever data source is used, it is critical that the barometric pressure readings accurately represent on-site conditions.

(vented); C) INW Submersible Pressure & Temperature Smart Sensor (PT2X) (vented); D) In-Situ Level TROLL (vented); and E) Onset MX2001 Bluetooth Water Level Logger (non-vented, but has a built-in barometer so you don't need a second (on-land) sensor; the barometer, which needs to be above water, is connected to the water level logger with a cable). The Onset HOBO U20 series are currently the most commonly-used pressure transducers at RMN streams. This does not constitute an endorsement or recommendation for their use; rather it is for descriptive purposes only.

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

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

4.2 Radiation shields and protective housings

Instream pressure transducers at RMN sites should be encased in housings to protect them from currents, debris, ice, and other stressors. Inexpensive housings can be constructed from 1.25-in or 1.5-in diameter Schedule 40 (or stronger) PVC pipe. Multiple 1/2-inch or larger holes should be drilled into the PVC to allow water to fluctuate at the same rate as in the stream (Figure 13). Factory-slotted PVC pipe with 0.010 slots, which is widely available for use in monitoring wells and piezometers, would also work well because it allows the free exchange of water while also keeping out fine sediments, debris, and biota. Some transducers, like the other one shown in Figure 13, come in protective metal cases and do not need to be encased in an additional housing. In streams that are subject to extended ice cover, the entire length of the transducer and the vented cable can be encased to prevent potential damage. If vandalism is a concern, the housings can be painted black or camouflage to make them less visible.

Figure 13. Example of a protective housing made of PVC pipe (left) that was used with a vented pressure transducer, which was secured inside the pipe with zip ties. Some transducers come in a protective metal case (right) and do not need to be encased in an additional housing.

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 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 13)
    - $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)

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 accessories can be used for the HOBO U20 series, temperature, and dissolved oxygen sensors (a photo of the couplers is shown in Figure 14). 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. The couplers (which come with the base station) make both devices compatible with the various HOBO sensors.

When processing non-vented pressure transducer data for the Onset U20 series sensors, you need to use the Barometric Compensation Assistant in HOBOware to obtain sensor depth or water level data. Instructions are available from Onset. Additional instructional materials were developed specifically for stream RMN partners and are available upon request (contact Britta Bierwagen (Bierwagen.Britta@epa.gov)).

Figure 14. 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.

4.4 Staff gauges

Staff gauges are encouraged at RMN sites when possible. If installed, they are used for reference level measurements during site visits, which are then used to verify transducer readings, and, in some cases, correct transducer data. In addition, if securely installed, the staff gauge can potentially provide an attachment point for the instream transducer. Figure 8 shows an example of a USGS style (Type A) gauge that is marked every 0.02 feet. This type of gauge is commonly used at RMN sites and costs approximately $40 (as of November 2019).

4.5 Elevation Survey

Elevation surveys at RMN sites are typically performed with the following equipment:

- Auto level or laser level
- Tripod
- Stadia rod
- Survey paint
- Survey nails
- Datasheet

Kits (that include the equipment listed above) are available starting around $450 (as of November 2019) but prices vary.

4.6 Discharge

The basic equipment needs for taking discharge measurements include:

- **Current meters** measure point velocity. Many different types are available, including mechanical meters (e.g., Price and Pygmy meters, which are vertical-axis meters), electromagnetic meters (e.g., Hach/Marsh-McBirney) and acoustic doppler velocimeters (e.g., Sontek Flowtracker).
- **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.

Equipment costs can be highly variable. Discounts are sometimes available for educational and governmental organizations. Below are approximate prices for several options, ranging from lowest to highest:

- USGS Pygmy current meter kit. Costs ~ $1,100. If you only have one site and/or limited funds, this could be an option. However, with this, you lose a lot of the QC capability you get with a more advanced set up like the SonTek FlowTracker2. In addition, you have to write measurements onto a field form, which leaves more room for error with data entry, transcription errors, etc.
- SonTek FlowTracker 2 ADV kit. The "cheap version" costs ~ $10,850 and includes a handheld display, probe assembly and wading rod.
- M9 RiverSurveyor. Costs $30,000+. Has many capabilities beyond the SonTek FlowTracker (e.g., can be used to create bathymetric maps, can be used in high flow systems where wading is not possible).

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 D. Sensor deployment and tracking form
- USEPA 2014 - Appendix J. Field forms for water level, elevation survey and flow measurements
- USEPA 2014 - Appendix K. Tips on record keeping and QA/QC during the data processing step

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.

If you are collecting time lapse images, your photos (as well as water level sensor data) can now be uploaded to the Flow Photo Explorer (https://www.usgs.gov/apps/ecosheds/fpe/#/). It is free and accessible to the public. The computer artificial intelligence (AI) component to Flow Photo Explorer is currently being developed to train computers to interpret water level from the stream images. For more information, visit the Flow Photo Explorer website and/or contact your EPA RMN regional lead.

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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)