Lake RMN Protocol Document.
Water level (12/28/2022)

Table of Contents

1 Level of effort 3

2 Visual readings 4

2.1 Protocols 5

2.1.1 Finding a suitable location 5

2.1.2 Installation of lake gauges or reference marks 6

2.1.3 Taking readings 7

2.2 Quality Assurance/Quality Control (QA/QC) 10

2.3 Equipment 11

2.4 Field forms/records 11

2.5 Data management 12

3 Continuous sensor measurements with non-vented pressure transducers 12

3.1 Protocols 13

3.2 Quality Assurance/Quality Control (QA/QC) 15

3.3 Equipment 16

3.4 Field forms/records 17

3.5 Data management 17

4 Literature Cited 18

Attachment A WI DNR Surveyor Protocol
Attachment B NPS-GLKN Water Level SOP (Elias et al. 2015)
Attachment C WI DNR Volunteer Lake Level Monitoring Program Protocol
Attachment D LOCSS-Training-Manual

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Why collect water level data?

Water level data are an important component of understanding overall lake processes. They help define the spatial extent of littoral zones, which are critical habitat for many aquatic organisms. Lake level data are also used for estimating lake volume, calculating residence time, and modeling pollutants (Elias et al. 2015). Lake level fluctuations affect lakeshore development, wetland conservation and function (Mitsch and Gosselink 2000), methylation[1] rates (which affect bioaccumulation of mercury) (Sorensen et al. 2005) and recreation (Figure 1). In many places, we have a limited understanding of natural water level fluctuations and how those fluctuations affect aquatic life. Water level data from RMN lakes could help fill this data gap and inform management decisions when setting permit thresholds in regulated lakes.

Figure 1. In some places, low water levels have stranded nearshore habitat, left piers hundreds of feet from shore and rendered boat landings unusable.

1 Level of effort

The RMN framework allows for different levels of effort to maximize participation. Table 1 contains a 'menu' of options for water level measurements, divided into three levels of participation: 'minimum', 'target' and 'better'. At a minimum, visual water level readings should be taken from a surveyed lake gauge or by measuring height in relation to a permanent reference mark once per month during the open water season. If resources permit, participants are encouraged to collect data at the 'target' or 'better' levels, since these 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. The 'target' level involves taking visual readings once per week (during the open water season), ideally on the same day and at approximately the same time. In addition, readings within 12 hours to 24 hours of substantive rainfall events are encouraged whenever possible. The highest level of participation involves deploying continuous sensors that record water level at hourly intervals. If continuous sensors are deployed, periodic visual water level readings should be taken as well since these measurements are used for sensor accuracy checks.

[1] Methylation is the process via which mercury converts from an inorganic to a toxic, bioavailable form called methylmercury. Methylmercury is easily absorbed into the living tissue of aquatic organisms, is not easily eliminated, and therefore accumulates in fish that are predators.

Looking ahead, we may be able to derive daily water level estimates from time lapse camera images using computer artificial intelligence (AI) that is being developed as part of the Flow Photo Explorer (https://www.usgs.gov/apps/ecosheds/fpe/#/). EPA regional leads will be applying for a grant in 2023 to add a lake AI component for estimating daily ice cover and water level. If you are deploying time lapse cameras at your lake, a good rule of thumb is to fill 80% or more of the image frame with the target (in this case, lake water). If you have the option of including a reference marker for water level (such as a staff gage or boulder in the water that is unlikely to move) in the photo frame as well, we encourage doing so.

Table 1. Water level measurements 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.*

Sampling location	Level of participation		
	Minimum	Target	Better
Gauges or reference marks are typically located near the shoreline. Continuous sensors are either located near the shoreline or are being deployed in the deep part of the lake*	Visual reading once per month (during the open water season)	Visual reading once per week (during the open water season) on the same day and at approximately the same time, plus readings within 12 hours to 24 hours of substantive rainfall events	Continuous sensors recording at 60-minute intervals*

*Two types of continuous sensors are being deployed: vented pressure transducers and non-vented pressure transducers. Vented pressure transducers are typically installed along the shoreline during the open water season (if left out during the winter, they are impacted by ice). The non-vented transducers are being deployed year-round, near the bottom of fixed vertical profile arrays (see the Lake RMN Vertical Profile protocols document). In addition to the in-water sensor, a second non-vented transducer is installed on land to compensate for changes in barometric pressure (which improves the accuracy of the 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. Section 2 describes the protocols for taking visual water level readings. These protocols are well-established and are based on guidance from WI DNR's Volunteer Lake Level Monitoring Program and the Lake Observations by Citizen Scientists & Satellites (LOCSS) network. Section 3 covers the protocols that RMN partners are using to deploy non-vented pressure transducers on vertical profile sensor arrays. These were developed by Shane Bowe (Red Lake Band of Chippewa Indians) and are currently being used by several RMN partners in the Northeast and Upper Midwest.

2 Visual readings

2.1 Protocols

The objective is to get as accurate a water level reading as possible from the same location during each site visit. The more frequently you can take readings, the better. If past water level measurements are available for a site, review those to get a sense of the range of water levels that the site will experience.

If resources permit (and the location is suitable), we recommend using WI DNR's Volunteer Lake Level Monitoring Protocols, which involve installing, surveying and reading a lake gauge during the open water season. The gauge is placed in the lake bed and shows the elevation of the water surface. It can be visually read from the shore or by boat. The elevation of the gauge is calibrated by referencing the numbered height on the gauge to the surveyed elevation of permanent reference marks on land (Harrelson et al. 1994). Surveying the staff gauge each year is essential as it enables water level readings to be linked across years. Installing and surveying lake gauges is not possible at all locations. As an alternate technique, we recommend using the NPS GLKN's protocols for establishing a reference mark. These protocols require a minimum of equipment (which makes them more practical for remote locations). A reference mark is a permanent marking (e.g., an 'X' etched into concrete, a bolt drilled into a structure) from which the water level measurement is always taken. If the elevation of the reference mark is established, it is called a bench mark (Elias et al. 2015).

In the ensuing subsections, we include excerpts from the WI DNR and NPS GLKN guidance documents on:

- Finding a suitable location
- Installing a lake gauge or establishing a reference mark
- Taking readings

The WI DNR gauge installation and survey protocols are included in their entirety in Attachment A, and the NPS GLKN Standard Operating Procedure (SOP) for measuring water level with reference marks is included in Attachment B. Attachments C and D contain guidance for taking water level readings based on the WI DNR and LOCSS protocols, respectively (the two sets of protocols match closely).

2.1.1 Finding a suitable location

Lake gauge (from WI DNR 2018). At some lakes, you may be able to install a lake gauge year-round on a permanent structure such as a bridge piling or weir. These types of installations are desirable because they involve the least amount of effort (you won't have to remove the gauge during the ice season and won't need to perform as many surveys). At RMN lakes where suitable permanent structures do not exist, and where the lakes freeze for part of the year, the gauges will need to be installed and removed from the same location each year to avoid ice damage. Temporary gauges like this are commonly attached to fence posts that are sunk into stable bottom substrate or anchored to bedrock (Elias et al. 2008). In Wisconsin, most lake gauges are installed and surveyed in the spring each year (April, or ice-out) and surveyed again before they are removed in October or November. The gauges need to be resurveyed and referenced to the same bench mark each year upon installation (Kenney 2010).

Lake gauges should be installed in locations that have as many of the following characteristics as possible:

- At a depth that can accommodate a large change in water level, but still near shore for accessibility.

- Away from general use navigation zones, but still visible from land (binoculars can be used if monitoring from land or dock) or accessible by boat (depending on how the person chooses to monitor the gauge) throughout the field season.
- Able to be efficiently monitored (i.e. facing a dock, toward shore, near volunteer's property).
- Near an existing elevation bench mark for ease of surveying.
- Not too close to shore if the lake bottom remains shallow over a long distance, as the gauge may come out of the water during times of low water (USACE Fact Sheet 2015).
- Adjacent to public land, or, if adjacent to private land, able to obtain a written agreement ("Release of Claims") for staff to access the property during the monitoring season without trespassing issues.

Reference mark (from NPS GLKN – Elias et al. 2015). RMN partners who are not able to install lake gauges can establish a reference mark instead. Water level measurements should be taken from the same reference mark each visit. Reference marks should be very stable and permanent (e.g., a mark on a bridge) to ensure consistent measurements from one year to the next.
Reference marks should be established in locations that have as many of the following characteristics as possible:

- Not obtrusive from a visitor's viewpoint, yet is easy to access and relocate.
- Above the current water level by at least 1 m to accommodate a large rise in level
- Relatively near the water's edge to allow viewing a stadia rod from the reference mark.

Tips:

- Install a back-up reference marker. This will ensure a continuous data record if something happens to the primary marker (e.g., it becomes dislodged due to frost heave or tampering).

2.1.2 Installation of lake gauges or reference marks

Lake gauge (from WI DNR 2018). The installation and the surveying of the lake gauge should be performed by professionally trained staff. If you lack the equipment and expertise to perform surveys, we recommend trying to find a partner from another agency who has the equipment and knowledge (such as USGS).

There are many techniques for installing lake gauges. WI DNR attaches the gauge and a mini-level to a wooden board, which is then attached to a metal fence post that is driven into the lake bottom. The gauge is then surveyed in and documented (by recording the latitude and longitude with a GPS unit, taking photos of the gauge and nearby landmarks and drawing a map). Figure 2 shows a gauge being installed and surveyed in. For detailed instructions on installing and surveying in lake gauges, see WI DNR's survey protocols in Attachment A.

If the gauge needs to be removed over the winter and reinstalled each spring, it should be resurveyed and referenced to the same bench mark each year upon installation (Kenney 2010).

Figure 2. Example of a lake gauge installation (left) and survey equipment, which typically includes a tripod, leveling instrument and stadia rod (right). The photos were provided by Minnesota DNR.

Reference mark (from NPS GLKN – Elias et al. 2015). Establishing a reference mark requires less equipment and expertise than installing a lake gauge. Reference marks can take many different forms: marks on bridges, buildings or other permanent structures, a steel or iron rod driven into a firm soil base, chiseled squares in concrete, file marks in bridge rails, or a cross or circle on a prominent point on a boulder in close proximity to the installation site (U.S. EPA 2014). A nail in a tree should only be used as a last resort as trees can grow substantially and cover the nails over the years. The NPS GLKN SOP (Attachment B) describes how to install an aluminum reference marker on exposed bedrock (Figure 3). Documenting the reference marker is very important so that the marker can be easily relocated during ensuing site visits. This is done by taking GPS coordinates and photos, drawing a map and writing a detailed description of its location.

Figure 3. Example of a reference mark installation during which a rock hammer was used to install an aluminum reference marker on exposed bedrock (left). The GPS coordinates of the marker were then recorded. The photos were provided by NPS GLKN.

2.1.3 Taking readings

Frequency. At a minimum, water level readings should be taken once per month during the open water season but more frequent readings are encouraged. The 'target' level involves taking visual readings once per week (during the open water season), ideally on the same day and at approximately the same time. In addition, readings within 12 hours to 24 hours of substantive rainfall events are encouraged whenever possible. The calmer the conditions, the better (winds should be calm to breezy with no large waves or white caps, as those will introduce more error).

Lake gauge (from WI DNR 2018, LOCSS 2019). There are three general steps:

1. Navigate to the gauge
2. Read the water level from the gauge
3. Inspect the gauge

When you are in position to take the reading, record the level at which the top of the water touches the gauge. Record the water level to the nearest 0.02 ft. If there are small waves as a result of a boat, wait for the water to calm before recording the measurement. If there are waves, observe the gauge for 30 seconds. Make note of the highest point that the waves reach, and the lowest point that the waves reach. Then report the average of the highest and lowest wave level. In your notes, record that there were large waves. The WI DNR protocols call for taking a picture as well (as a QA/QC measure; see Section 2.2).

After taking the reading, inspect the mini-level on the gauge to determine whether it has been bumped or disturbed. If the bubble is centered between the lines, then the gauge is okay. If the bubble is not centered between the lines, then the gauge has been moved or bumped, and this should be reported (since the gauge will need to be resurveyed).

Instructions for reporting water level measurements vary depending on what network you are part of. If you are participating in the LOCSS network, they will send you a sign with instructions on how to submit data via text, email or online (see Figure 4 and Attachment D). The sign should be attached to the gauge post. RMN partners are encouraged to join or collaborate with LOCSS. If desired, LOCSS will house RMN water level data and provide online visualization tools (https://www.locss.org/view-lake-data). There is a training video on how to take measurements on the LOCSS website (https://www.locss.org/get-involved).

If you have a gauge that you remove during the winter, clean both the gauge and the fence post with a scrub brush before storing for the winter, making sure to remove and rinse off any mud, plant material, mussels, or other visible organic material that is attached to the gauge and/or fence post. Pay particular attention to any holes or crevices in the equipment during the cleaning process. Use baking soda to help clean gauge plates that are especially dirty.

Figure 4. Examples of signs from the LOCSS network (left) and WI DNR (right) with instructions on how to submit readings. The gauge on the right shows a mini-level; this should be checked during each visit (the bubble should be centered; otherwise the gauge has been moved and needs to be resurveyed).

Reference mark (from NPS GLKN – Elias et al. 2015). There are a number of techniques for taking water level readings from reference marks. To minimize potential sources of error, use a firm surface on which to set the surveyors rod (e.g., a rock or a Secchi disk) and a firm surface on which to place the eye level (e.g., a piece of 2 × 4 lumber or the clipboard). The NPS GLKN protocols call for making the reading to the nearest 0.1 cm. If the reference mark is located above the water level, the reading should be recorded as a negative number. If the reference mark is below the water level, the measurement should be recorded as a positive number. The NPS GLKN SOP (Attachment B) describes two methods for taking readings when the reference marker is located above the water level. One uses a stadia rod and hand-held eye level (see Figure 5); the other uses a stadia rod, line and line level. The NPS GLKN SOP also shows an example of a measurement taken from a reference marker that is located under water.

If for some reason a new reference marker needs to be used, 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 cannot be compared because the markers will likely be located at different elevations above the land-water interface.

Figure 5. Example of a measurement technique in which a stadia rod is held at the water's edge and a hand-held eye level is positivioned (Holding stadia rod at water's edge (left), viewing stadia rod through hand-held eye level (right). The photos were provided by NPS GLKN.

Time lapse cameras. Looking ahead, we may be able to derive daily water level estimates from time lapse camera images using computer artificial intelligence (AI) that is being developed as part of the Flow Photo Explorer (https://www.usgs.gov/apps/ecosheds/fpe/#/). EPA regional leads will be applying for a grant in 2023 to add a lake AI component for estimating daily ice cover and water level. If you are deploying time lapse cameras at your lake, a good rule of thumb is to fill 80% or more of the image frame with the target (in this case, lake water). If you have the option of including a reference marker for water level (such as a staff gage or boulder in the water that is unlikely to move) in the photo frame as well, we encourage doing so. Images can be uploaded to the Flow Photo Explorer.

2.2 Quality Assurance/Quality Control (QA/QC)

QA/QC is a critical component of monitoring, as it ensures data quality objectives are being met. Oversight and compliance is left up to participants.

Recommended QA/QC protocols at RMN lakes include:

- Conduct a training for staff who will be taking water level measurements
- Emphasize the importance of taking the measurements from the same location over time (having a high accuracy GPS unit may help with this)
- Avoid taking measurements when there are big waves
- Consider using binoculars (where appropriate) to improve the accuracy of your readings
- Take duplicate readings. There are different options for this. Either listed here are suitable -

  - NPS GLKN (Elias et al. 2015). If you have two field crew members, repeat your measurement with field personnel switching roles. Both readings should be recorded on the field data sheet, along with the average. If the repeated measurements differ by 10 cm or more, both readings should be repeated.
  - WI DNR (2018). Conduct an audit. Either have a professional staff member coordinate with the person on a site visit in the field, and have each person record independent lake levels and then compare results. An acceptable margin of error between duplicate readings is 0.02 feet. Or have a professional staff member make an unannounced, solo visit to the lake gauge and take an independent reading on the same day as the other person.
- For lake gauge readings, consider taking a photo - it can be used to double check the quality of the data (WI DNR 2018).
- For lake gauge readings, be sure to check the bubble in the mini-level; if it is not centered, the gauge has been moved or bumped and should be resurveyed. Make a note about the bubble reading during each site visit.
- Review the water level reading from the most recent site visit; if it differs from the new reading by more than 0.2 feet, verify that the new water level is indeed correct.
- If you are conducting surveys, the equipment should be properly calibrated. Also, on the day of installation, replicate the survey of the staff gauge and reference marks (see WI DNR protocols in Attachment A). The two readings should agree within 0.01 ft. or the survey should be completed for a third time. Use the first of the two readings to define lake levels for the season.

2.3 Equipment

The WI DNR (2018) and NPS GLKN (Elias et al. 2015) protocol documents each have equipment lists. Here is a general compilation of equipment to bring on site visits -

- Field notebook
- Photos and description of location
- Data sheets
- Binoculars
- GPS unit and spare batteries
- (Initial visit) Appropriate tools for installing a lake gauge (see list in Section III of Attachment A) or reference marker (see Section 4.3 of Attachment B)
- Appropriate tools for taking measurements from reference markers (e.g., eye level or line and line level, stadia rod)

If performing surveys, reference Section III of Attachment A (WI DNR 2018).

2.4 Field forms/records

During site visits, you should record date, time, site ID, water level, comments on wind/wave conditions plus notes on any other things that might affect the quality of the water level measurement. If the site has a lake gauge with a mini-level, record whether the bubble is okay.

Attachments C (WI DNR) and D (LOCSS) contain example field forms.

2.5 Data management

Most RMN partners do not have a system in place for storing and managing water level data (with some exceptions, like WI DNR and MN DNR). For people in this situation, we recommend contacting LOCSS and asking to join their network. They will house your data and provide online visualization tools (see example in Figure 6). An added bonus is that your data can be used to help improve their remote sensing applications. Information on how to join the network can be found on the LOCSS website: https://www.locss.org/get-involved.

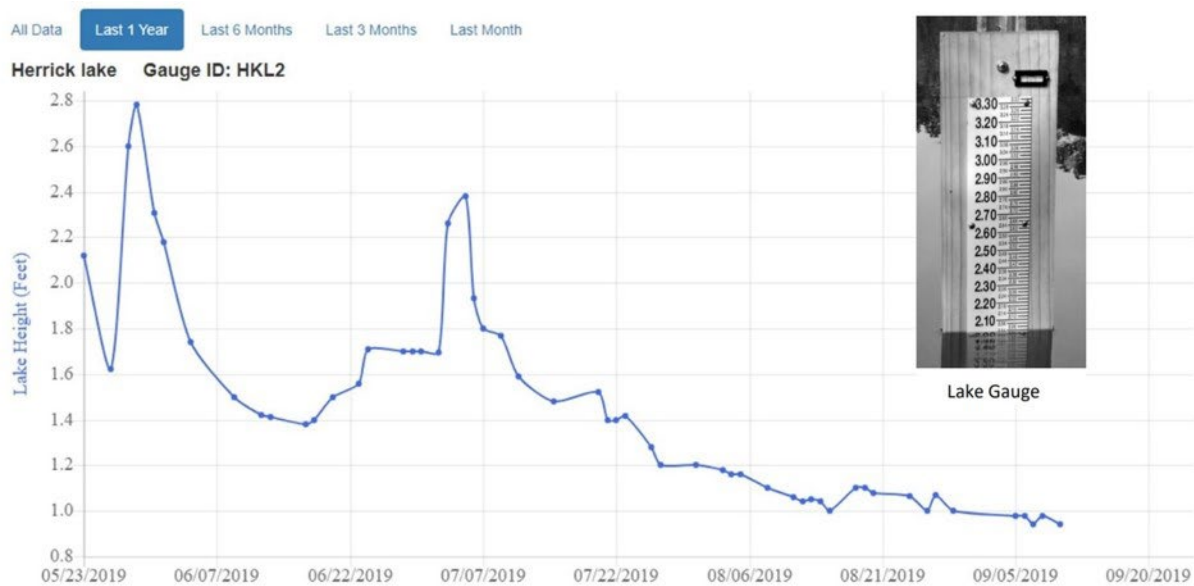

Figure 6. Example of the data visualization tools available on the LOCSS website (https://www.locss.org/get-involved). The dots are from weekly (with exceptions) lake gauge readings (the lines that connect the dots but do not represent actual observations).

3 Continuous sensor measurements with non-vented pressure transducers

The highest level of water level data collection at RMN lakes involves collecting hourly measurements with continuous sensors. Two types of water level sensors have been used at RMN lakes: vented and non-vented pressure transducers. Transducers record absolute pressure (air pressure + water pressure), from which air pressure must be subtracted to yield water pressure. Software can then be used to convert water pressure to water level using the density of water. U.S. EPA (2014) contains a more detailed overview of the differences between vented and non-vented transducers.

In this document, we only cover non-vented pressure transducers. This is not because non-vented transducers are better than vented transducers; rather it is because we have limited resources to write this protocol document and non-vented transducers are being used at more RMN lakes at this time. If you would like information on vented transducers, MN DNR has been using them and is happy to share information on their experiences. Contact Casey Schoenebeck (casey.schoenebeck@state.mn.us). Another resource is Wagner et al. 2006 (by USGS).

The protocols we describe were developed by Shane Bowe (Red Lake Band of Chippewa Indians) and have been successfully used by several lake RMN partners since 2018. They involve attaching a non-vented pressure transducer to a fixed vertical profile array of sensors, typically located in the deepest point of lakes. In addition, a non-vented pressure transducer is also deployed on land[2] so that adjustments can be made for changes in barometric pressure (this is needed because atmospheric pressure changes with weather; failure to compensate for these variations could result in errors in the water level measurements). In this document, we describe how to deploy non-vented pressure transducers on fixed vertical profile sensor arrays as well as on land. For detailed instructions on assembling and deploying vertical profile arrays, reference the Lake RMN Vertical Profile protocols document.

3.1 Protocols

At RMN lakes, fixed vertical profile sensor arrays are being deployed, typically at the deepest point in the lake. Efforts are made to keep the arrays in the exact same location over time. The arrays are being deployed either seasonally or year-round. There are many design possibilities, as described in the Lake RMN Vertical Profile protocols document. Figure 7 shows a two-buoy design (provided by the NPS-GLKN network) that several RMN partners have used successfully since 2018.

The non-vented pressure transducer is attached to the instrument line. Initially we recommended that the sensor be attached near the bottom of the instrument line to minimize movement if the line sways. However, there is a trade-off between depth and sensor accuracy (as you get into the larger depth ranges, you lose accuracy) so we now recommend that sensors be deployed somewhere in the 4 to 9-meter range (the 9-m cut-off allows for use of the 0 to 30 ft (9-m) sensor; see Section 3.3). We'll continue to refine this recommendation as we gain more experience. If you change the depth of the water level sensor, this needs to be carefully documented so that water levels can be adjusted accordingly to maintain continuity in the long-term record.

In addition, a second non-vented pressure transducer is installed on land to account for changes in barometric pressure (Figure 7) (note: if there is an existing on-land non-vented pressure transducer that is nearby and representative of conditions at the site (e.g., at a similar elevation), it is ok to use that instead). The non-vented pressure transducers record temperature in addition to water pressure. To be consistent with typical meteorological observations, the on-land transducers should be placed at a height of 2 meters, or approximately 6 feet, off the ground, which, in most cases, should also be high enough to protect the sensor from high flows and snow packs. Where available, trees typically make good attachment points for the on-land transducers because they provide stability, some degree of shade, and can help hide the sensor from potential vandals. If a suitable tree is present, attach the sensor to its north side, out of direct sunlight (to minimize temperature variations). The closer the tree is to the in-water sensor, the better.

[2] In some situations, data from a nearby weather station may be used (instead of deploying a second transducer) but on-site deployments are generally preferred at RMN lakes.

Radiation shields help improve the accuracy of the temperature measurement. Most RMN partners are making shields made of PVC (like the one shown in Figure 7). Holes should be drilled in the bottom of the PVC housing to prevent condensation and laterally blown rain and snow from filling the cup to a depth sufficient to inundate the ports through which the barometric pressure is compensated. If this occurs, the "barometric pressure" becomes barometric pressure plus a small amount of pressure due to this accumulated water, and the data cannot be used. This issue can also be addressed by deploying the barometric pressure sensor upside down, so that the port tip is on top. Some people have had issues with wasps or spiders building nests in the shield. Covering the holes with fiberglass mesh usually works well as a preventative measure. More detailed information on deploying the on-land transducer can be found in U.S. EPA 2014.

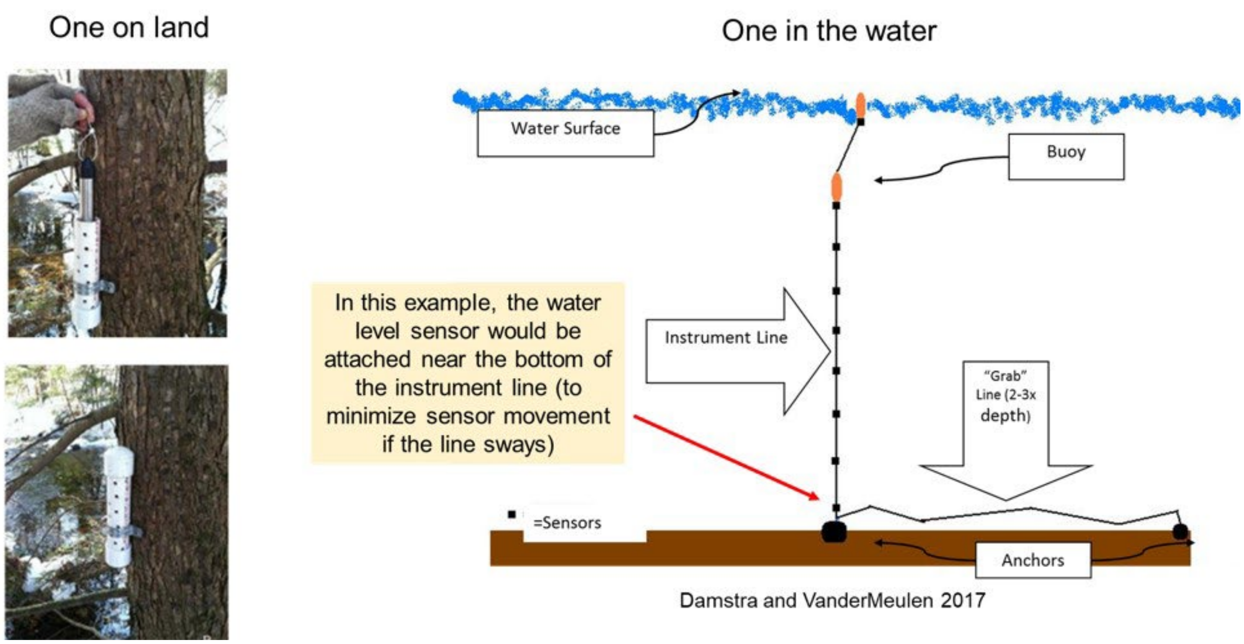

Figure 7. RMN partners are attaching a non-vented pressure transducer to the instrument line. In addition, a non-vented transducer is being deployed on land to compensate for changes in barometric pressure.

The water level sensors should be configured to record at 60-minute intervals (or less if desired) at RMN lakes. To make the data processing steps faster and easier, we recommend that sensors are:

- Programmed to record on the hour (xx:00).
- Record in consistent units (for the Onset sensors, we generate pressure outputs in 'psi' and depth or water level outputs in 'ft')
- 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

All sensors on the same instrument line should be programmed to record at the exact same time.

If available, consider using the "delayed start" feature so that sensors don't start recording until several hours after they are in position and have time to stabilize. This saves you from having to remove the first several data points later on during data processing. Instructions for launching and configuring Onset

HOBO sensors are available on the ContDataQC website (https://nalms.shinyapps.io/ContDataQC/; go to the Sensor configuration section of the Main Functions – QC tips tab).

After doing the initial deployment, there is flexibility in the timing of follow-up visits, especially if you are only collecting temperature and water level data. Most RMN partners are doing two downloads a year (in the spring after ice-off and in the fall before ice-on) which seems to strike a good balance between workload (number of site visits), catching potential problems and causing movement of sensor arrays (each time the array is removed to download data and returned to position, sensor depths may shift slightly, which is reflected in the water level data).

To download data from the in-water sensor, pull up the instrument line (with all of the other sensors) into the boat. While doing so, watch out for fish hooks and beware of zip ties breaking when you pull the array over the gunnel of the boat. Write the time the sensors are out of the water on the field form. Take care not to damage any sensors and flake the instrument line into the boat. Use the appropriate device(s) to download the data (download instructions will vary across sensors).

Before downloading the data, check the sensor for fouling (e.g., from algae) and note anything else that might have affected the accuracy of the measurements during the deployment period on the field form. Also, if you have a laptop in the field, check the sensor batteries (if using the Onset HOBO sensors, the batteries typically last 5-6 years if they are set to record at 60-minute intervals).

After downloading the data, make sure you follow the appropriate procedures for relaunching the sensors so that they continue to record at the desired interval at the top of the hour and clear/format the sensor memory to free up space and prevent carry over of the previously recorded data. Then put the instrument line/sensor array back into the same location as before (or as close as you can get). A similar procedure is used when downloading data from the on-land sensor (except instead of pulling up an instrument line, remove the sensor from the housing/radiation shield and download the data).

If you are using Onset HOBO sensors, instructions for configuring sensors and downloading data are available upon request from Jen.Stamp@tetratech.com

In addition to the continuous sensor data, RMN partners are encouraged to take reference water level measurements. These are discrete measurements taken from a fixed reference point such as a lake gauge or a reference mark (as described in Section 2.1.2). Reference water level measurements enable you to obtain water level in relation to a meaningful fixed reference point (such as a lake gauge) that should not change over time. If taken at the beginning and end of each deployment period, these measurements can also be used to detect and compensate for sensor drift.

3.2 Quality Assurance/Quality Control (QA/QC)

Recommended QA/QC procedures for the continuous sensor arrays are to:

- During each site visit, take a depth measurement at the instrument line, using the following procedures to the best of your ability:
    - Take measurement as close as possible to the in-water sensor and as close as possible to the time when the sensors are recording measurements (e.g., top of the hour).
    - Note on the field form whether the time of your measurement is standard or daylight savings time.

    - We recommend taking the measurement with a line that hangs vertically and touches the bottom, such as a field meter on a cable, a measuring tape attached to the same anchor that is being used for the instrument line (to get a feel for how much it is likely to sink in the bottom substrates), brass chain, or a plumb line attached to a measuring tape to obtain an accurate depth at the site rather than relying on sonar depth finders or bathymetric maps.
    - When you view the sensor data at a later time, compare the measurements. They should be close but won't be exactly the same (depending on how far above the bottom the sensor is deployed; and the exact sensor depth is difficult to determine without diving down and measuring the distance of the sensor from the bottom). If there is a big discrepancy and inconsistencies over time, something is likely wrong.
- During each site visit, take a reference water level measurement, using the procedures described in Section 2.1.2 (the reference mark could be a lake gauge, or mark on a permanent structure such as a rock). When you view the sensor data at a later time, compare the measurements and check for sensor drift (if the difference is outside the accuracy specs of the sensor, it is possible that drift may have occurred, which can be corrected for).
- Keep careful notes documenting anything that could affect the sensor readings (e.g., any signs that the sensor was fouled, moved, disturbed or sagged; note when sensors are changed out; note when instrument lines or depths of sensors are adjusted). Any of these things could affect long-term trends (the changes may be mistakenly interpreted as a trend in the parameter when it's just a physical change in position).

3.3 Equipment

Most RMN partners are using the Onset HOBO U-20 series non-vented pressure transducers shown in Figure 8. There are two series: U20 and U20L. Both series are available in 4 water depth ranges: 0 to 13 ft (4-m); 0 to 30 ft (9-m); 0 to 100 ft (30.5-m) and 0 to 250 ft (76-m). Select the depth range that is sufficient for the expected variation in water level at the lake. Chose the smallest range that will encompass all expected water levels. This is important because accuracy is a function of the operational range of the transducer. 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). The U20 series transducer costs $555 (as of 5/2022) and the U20L series transducer costs $330. The cheaper U20L should work fine at RMN lakes for the on-land transducer.

- Two series:
  - **U20** - higher performance, silver, stainless steel housing for freshwater systems, price $495 (6/2019)
    - Titanium housing for saltwater systems ($595) (6/2019)
  - **U20L** – lower performance, black, polypropylene housing, lower price ($299)
- Measures temperature as well as pressure (accuracy ± 0.44°C)
- Self-contained, non-vented loggers for easy deployment.
- Optic USB interface allows fully sealed housing with no mechanical connectors to fail.
- Durable ceramic sensor can withstand being frozen.
- Batteries – factory-replaceable; 5-year battery life under typical use*
  - *varies based on logging interval, temperature and other factors

Figure 8. Onset HOBO U20 and U20L series non-vented pressure transducers, which have the characteristics described above. This is not an endorsement. Other brands exist as well.

In addition to the sensors themselves, depending on the brand, you may need accessories to configure, launch, download and work with the sensor data. The Onset HOBO U20 and U20L series require the following additional equipment:

- Onset HOBO download devices (need one or the other)
  - base station - $140
  - waterproof shuttle - $280
- Proprietary software –
  - Onset HOBOWare Pro ($75 online (download only); $99 CD) - the 'Pro' version is needed to generate sensor depth or water level

An equipment list for the full sensor array (instrument line, anchors, buoys, etc.) can be found in the Lake RMN Vertical Profiles protocol document.

3.4 Field forms/records

Field forms have not been developed for lake RMNs. However, there are some examples that were developed for stream RMNs that could potentially be adapted for water level sensors in RMN lakes. These can be found in the following sections of the 2014 U.S. EPA Best Practices for Continuous Monitoring of Temperature and Flow in Wadeable Streams report[3]:

- U.S. EPA (2014) - Appendix G. This has a mid-deployment/maintenance check form that is completed during each site visit. You would need to replace the references to temperature sensors with water level sensors. For accuracy checks, replace temperature with depth and reference level measurements.
- U.S. EPA (2014) - Appendix K. This has tips on record keeping and QA/QC during the data processing step. Section K4 has a sample form.

3.5 Data management

[3] https://cfpub.epa.gov/ncea/risk/recordisplay.cfm?deid=280013&inclCol=global

Each RMN partner must act as custodian of their own continuous water level 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, it can calculate basic statistics (daily/monthy/seasonal/annual time periods) and generate time series plots like the time series plot shown in Figure 9. For more information, contact Jen.Stamp@tetratech.com

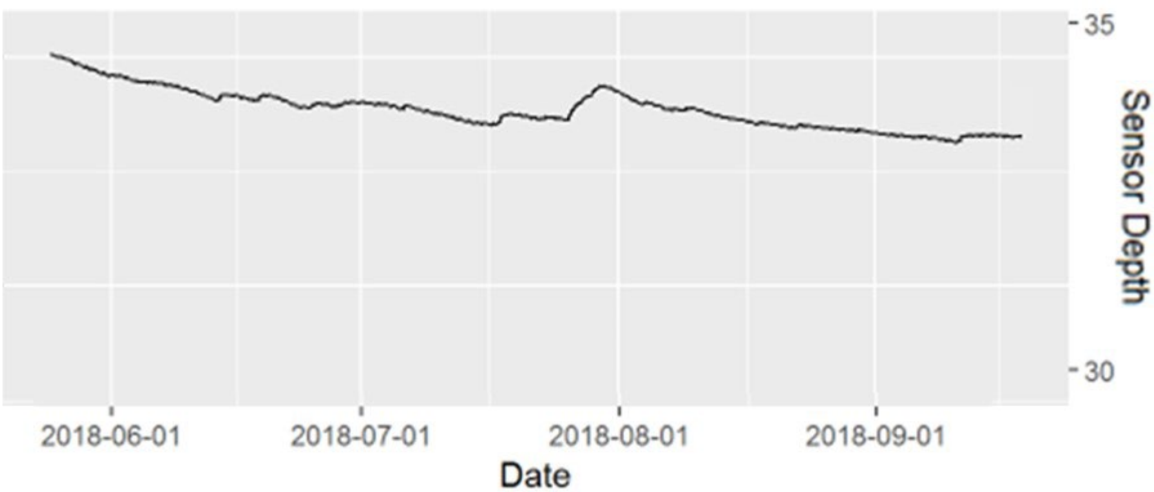

Figure 9. Time series plot generated from hourly measurements from a water level sensor deployed year-round at a Vermont lake. This plot was generated with the ContDataQC tool (https://github.com/leppott/ContDataQC).

4 Literature Cited

Elias, J. E, R. Axler, and E. Ruzycki. 2008. Water quality monitoring protocol for inland lakes. Version 1.0. National Park Service, Great Lakes Inventory and Monitoring Network. Natural Resources Technical Report NPS/MWR/GLKN/NRTR—2008/109. National Park Service, Fort Collins, Colorado.

Elias, J., R. Wise, and D. VanderMeulen. 2015. Standard operating procedure #4: Measuring water level. *In* J. E. Elias, R. Axler, E. Ruzycki, and D. VanderMeulen. 2015. Water quality monitoring protocol for inland lakes: Great Lakes Inventory and Monitoring Network, version 1.1. Natural Resource Report NPS/GLKN/NRR—2015/1027. National Park Service, Fort Collins, Colorado.

Harrelson, C. C, C. L. Rawlins, J. P. Potyondy. 1994. Stream channel reference sites: an illustrated guide to field technique. Gen. Tech. Rep. RM-245. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station.

Kallemeyn, L. W., K. L. Holmberg, J. A. Perry, and B. Y. Odde. 2003. Aquatic synthesis for Voyageurs National Park. Information and Technology Report USGS/BRD/ITR—2003-0001. U.S. Geological Survey, Columbia Environmental Research Center, International Falls Biological Station, International Falls, Minnesota. Available at www.cerc.usgs.gov/pubs/center/pdfdocs/ITR2003-0001.pdf.

Kenney, T.A. 2010. Levels at gaging stations: U.S. Geological Survey Techniques and Methods 3-A19.

Lake Observations by Citizen Scientists & Satellites (LOCSS) network. Accessed 5 November 2019. http://lakelevel.web.unc.edu/lake-data/

Mitsch, W. J., and J. G. Gosselink. 2000. Wetlands, 3rd edition. John Wiley and Sons, New York, New York

Sorensen, J. A., L. W. Kallemeyn, and M. Sydor. 2005. Relationship between mercury accumulation in young-of-the-year yellow perch and water-level fluctuations. Environmental Science and Technology 39:9237–9243.

U.S. Army Corps of Engineers Fact Sheet (accessed 2/4/2015) http://www.nwo.usace.army.mil/Media/FactSheets/FactSheetArticleView/tabid/2034/Article/487672/staff-gauge-setup-instructions.aspx

Wisconsin DNR (WI DNR). 2015. Lake Level Monitoring Surveyor Protocol, version 1.

Wisconsin DNR (WI DNR). 2016. Lake Level Monitoring Protocol, version 2.

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 D.C. EPA/600/R-13/170F.

Vana-Miller, D. 2002. Water resources management plan for Sleeping Bear Dunes National Lakeshore. National Park Service, Water Resources Division, Fort Collins, Colorado.

Wagner, R.J., R.W. Boulger, Jr., C.J. Oblinger, and B.A. Smith. 2006. Guidelines and standard procedures for continuous water-quality monitors—Station operation, record computation, and data reporting: U.S. Geological Survey Techniques and Methods 1–D3, 51p.+8attachments; accessed August 30, 2011, at http://pubs.water.usgs.gov/tm1d3.