Lake RMN Protocol Document.
Vertical Profile (12/28/2022)

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Acknowledgements:
The document was written by Tetra Tech (Jen.Stamp@tetratech.com), with funding from EPA ORD CPHEA (EPA lead: Britta Bierwagen - Bierwagen.Britta@epa.gov), Shane Bowe (Red Lake Band) and the Bureau of Indian Affairs (BIA). The protocols were developed through a collaborative process with Regional Monitoring Network (RMN) partners. Special thanks to Casey Schoenebeck and Tim Martin from MN DNR, Shane Bowe (Red Lake Band of Chippewa Indians), Rick Damstra and David VanderMeulen from the NPS - Great Lakes Network (GLKN) and Julia Daly, University of Maine Farmington.

Why take vertical profile measurements?

Vertical depth profiles provide information on lake mixing/stratification patterns and availability of appropriate oxy-thermal habitat to support aquatic life. A modeling study by Butcher et al. (2015) on the sensitivity of lake thermal and mixing dynamics to future thermal and hydrologic conditions suggests that the extent and strength of lake stratification is likely to increase. Earlier thawing of winter ice can contribute to earlier onset of lake stratification, which in turn could exacerbate the extent and duration of hypoxic or anoxic conditions in the hypolimnion (Jankowski et al. 2006, Jane et al. 2022). Warming temperatures and changing lake stratification patterns may negatively affect cold water fish (Jacobson et al. 2012) and allow organisms like bloom-forming cyanobacteria to gain a competitive advantage over other phytoplankton groups, which could contribute to increases in harmful algal blooms (Jöhnk et al. 2008, Wagner and Adrian 2009, Paerl and Paul 2012).

1 Level of effort

The RMN framework allows for different levels of effort to maximize participation. Table 1 contains a 'menu' of options for vertical profile measurements, divided into three levels of participation: 'minimum', 'target' and 'better. The highest priority parameter is temperature, followed by DO. Continuous temperature and DO sensors are encouraged when possible. Conductivity and pH measurements are optional but encouraged during discrete profiles if the field meter has the appropriate probes.

At a minimum, discrete vertical profile measurements should be taken once per year at the deep point in the lake during the July 24-August 7 time period. While efforts should be made to sample during this time period whenever possible, situations may arise where people need to monitor during the week before or after. Those data will still be used but will be marked for further evaluation.

The July 24-August 7 time period is when lake temperatures are typically warmest and chlorophyll-a tends to reach its annual maximum. This is also a time when the lake is likely to be stratified (if it stratifies at all) and dissolved oxygen is likely lowest in the hypolimnion. Many lake monitoring programs typically sample around this time.

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, particularly if trends are subtle (USEPA 2016). Attachment A describes the added value of year-round, high frequency measurements. Even if continuous sensors are deployed, discrete vertical profile measurements should still be taken (ideally during each site visit) and used for sensor accuracy checks.

Table 1. Vertical profiles 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 (e.g., monthly or bi-weekly discrete measurements).

Sampling location	Level of participation		
	Minimum	Target	Better
Deep point	Discrete annual profile during July 24-August 7*	Discrete profiles during spring turnover + 3X/year during summer (15 July – 15 Sept*); one of the 3 visits should occur during the July 24-Aug 7 time period	Continuous temperature and DO** sensors deployed year-round (see Table 6 for recommendations on depths), recording at 60-minute intervals; discrete vertical profile measurements are taken during each site visit.

*Some flexibility (a week on either end of these time periods) is acceptable.
**Temperature is the highest priority parameter for the RMNs, followed by DO

2 Discrete Vertical Profile Measurements

2.1 Measurements

Discrete profiles are taken from the deep point in RMN lakes. The data should be collected from the same location each time. The measurements are typically taken with multi-parameter meters but some people use temperature sensors alone (see Section 2.3). At a minimum, profile measurements should be taken once during the July 24-August 7 time period[1]. More measurements are encouraged if possible, particularly during the period July-September. Discrete profile data should be reported even if continuous sensors are deployed since the discrete measurements are used for sensor accuracy checks.

If you already have existing USEPA-approved Standard Operating Procedures (SOPs) and/or Quality Assurance Project Plans (QAPPs) for taking discrete profiles for temperature, DO, pH and conductivity, keep collecting data in accordance with your approved methods. If you do not have existing SOPs or QAPPs for all of the parameters, use the USEPA National Lake Assessment (NLA) protocols (USEPA 2017), which we describe below. Your RMN regional lead can also provide resources that will help you develop your own approved sampling plans (for example, the Great Lakes Inventory and Monitoring Network (GLKN) has an excellent, comprehensive document with much if not all of the information you would need – see Elias et al. 2015). To find out who your regional lead is, contact Britta Bierwagen (Bierwagen.Britta@epa.gov).

RMN/US EPA NLA (2017) protocols are as follows -

Pre-trip preparations

[1] While efforts should be made to take a discrete profile during this time period, situations may arise where you need to sample during the week before or after. Those samples will still be used but will be flagged for closer evaluation.

- Review protocols
- Make sure you have necessary permissions to access the lake and collect data
- Prepare equipment
  - Use a trip specific checklist of equipment and supplies
  - Calibrate multi-probe meters in accordance with manufacturer specifications (see Section 2.2 for general guidance; Appendix A contains an example form that can be used to document the calibration)
- Document preparation
  - Prepare lake monitoring data sheets with the specific site/date information relevant to the sampling event
- Bring decontamination materials

Travel to sampling site

- Navigate to the predetermined sample location(s) (the deep point in the lake) via GPS
- Stop the boat and lower the anchor; ensure the boat is not drifting.
  - For all sampling, it is critical to avoid sampling water showing evidence of oil, gasoline or anything else from the boat. It is best to kill the engine and set the anchor, however we understand this may not be possible in bad weather or with a balky engine.
- Take a depth measurement to verify that the correct location is being sampled

Take vertical profile measurements

- Whatever instrument you use should be properly calibrated and maintained in accordance with an approved SOP or QAPP and/or manufacturer specifications (see Section 2.2 for general guidance; Appendix A contains an example form for documenting the calibration).
- Record measurements at appropriate depths (see example field form in Appendix A, from USEPA 2017). Before recording measurements, wait until the numbers stabilize to ensure that the sensors have equilibrated to the condition of the water being monitored
  - Collect as many of the four parameters as you can (temperature, DO, pH, conductivity; at a minimum, record temperature. DO is the next highest priority; note: some RMN partners are starting to use chlorophyll probes as well, which are also of interest (but are optional).
  - If you already have an USEPA-approved SOP or QAPP with protocols for taking vertical profile measurements, follow your existing protocols. If you do not have existing guidance, use the USEPA NLA protocols (USEPA 2017), which call for sampling at the following depths[2] (see Figure 1 for examples) –

    - <u>Sites with a maximum depth ≤ 3 m</u>
      - Just below surface
      - 0.5-m intervals
      - 0.5-m from bottom

    - <u>Sites with a maximum depth 3-20 m</u>
      - Just below surface
      - Every 1-m ending at 0.5-m from bottom

[2] If the discrete measurements are being used for accuracy checks on sensor arrays, and the depths listed above do not overlap with the depths of the sensors, take measurements both at the depths listed above as well as at the sensor depths (to the best of your ability; for more information, see Text Box #3).

- Sites with a maximum depth (>20 m)
    - Just below surface
    - Every 1-m up to 20-m
    - Then every 2-m ending at 0.5-m from bottom, with this exception -
        - Within the metalimnion, take measurements at least every 1 meter.

While sampling, determine the top and bottom of the metalimnion

- In keeping with USEPA NLA protocols, we are defining the metalimnion as the region of the profile where temperature changes at a rate of 1˚C or more per meter (see example in Table 2)
    - If the lake is thermally stratified, note the top and bottom of the metalimnion on the field form (Appendix A):
        - Top (T) = rate of change becomes ≥ 1°C/meter
        - Bottom (B) = rate of change becomes < 1°C/meter
    - NOTE: If you suspect that the metalimnion exists but does not change at the specified rate, estimate the top and bottom of the metalimnion as best you can, flag the data, and explain.

Table 2. Example profile for a lake with a bottom depth of 10m (source: NH DES VLAP manual)

Depth (m)	Temperature (Celsius)	Dissolved oxygen (mg/L)	Thermal layers
0.1	17.0	8.59	Upper layer (epilimnion)
1	17.0	8.57	
2	16.9	8.50	
3	16.8	8.50	
4	16.5	8.47	
5	13.4	2.58	Thermocline (metalimnion)
6	9.7	1.88	
7	8.0	0.21	
8	6.8	0.18	Lower layer (hypolimnion)
9	6.3	0.18	
9.5	5.9	0.17	

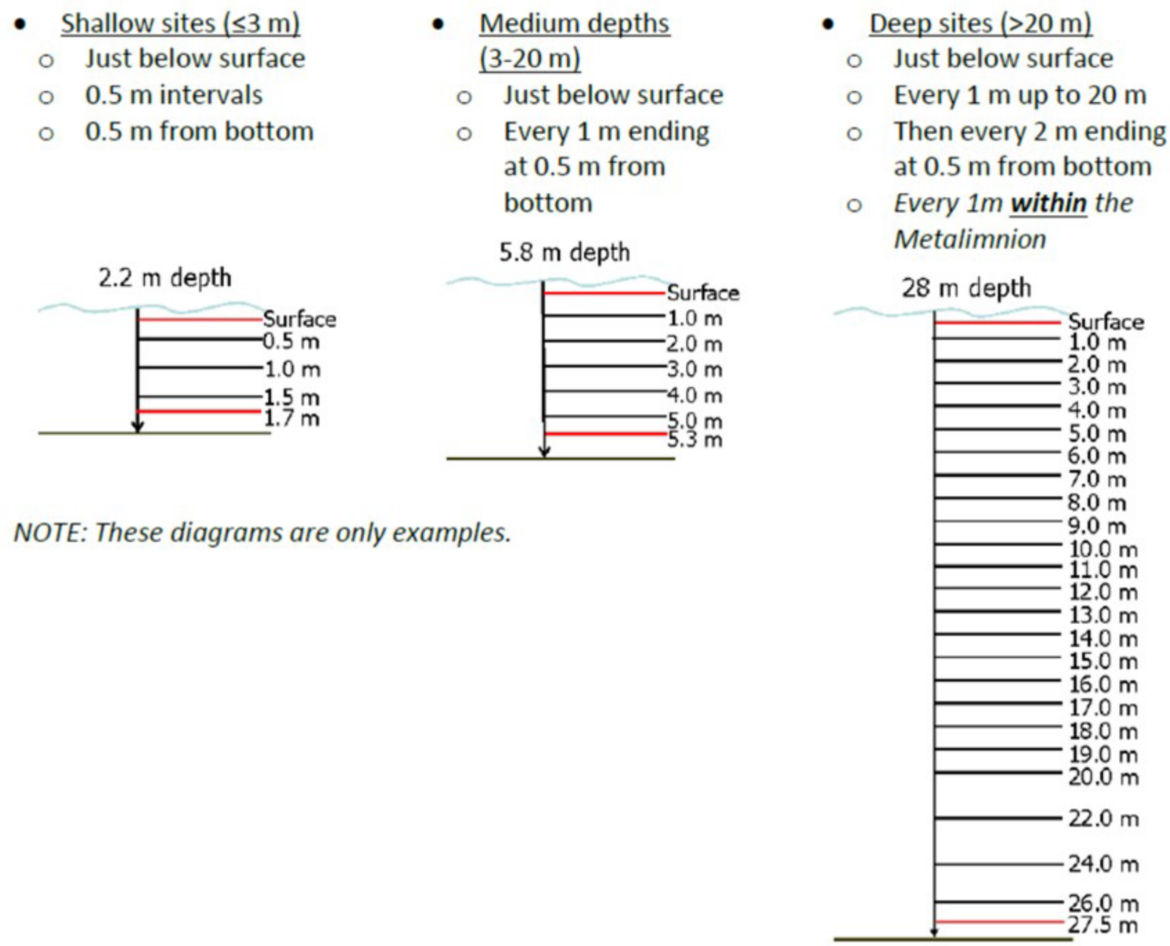


Figure 1. Examples of profile intervals for shallow, medium and deep sites (USEPA NLA 2017).

REMINDERS:

- Intervals are dependent upon the depth; thus, an accurate initial depth measurement is important.
- Try not to let the sonde touch bottom while sampling.
- Always take 1st measurement just below surface, and final measurement 0.5 m from bottom. For QC purposes, as you raise the sonde, we encourage also taking a final repeat reading at the first subsurface depth (0.5 or 1.0 m)
- We recommend marking the sonde cable in 0.5-meter increments (so the cable can serve as a back-up for the sonde depth sensor, if present).
- Measurements should be taken from the same location each visit. If you drift from the deep spot while taking the measurement, pull up the anchor, move back to the deep spot, re-deploy the anchor and take the measurements over again.

We expect participating entities to follow their own approved safety protocols and thus do not provide any here.

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 are left up to participants.

QA/QC at RMN lakes should include the following:

- Calibration of the instrument
- Verify the readings on the way up

Use calibrated instruments for all field measurements. Table 3 summarizes the target calibration frequency and minimum acceptance criteria for water temperature and DO (Elias et al. 2015, SOP #6). Calibration solutions should be used for conductivity and pH (optional parameters). Our protocols provide only generic guidelines for equipment use and maintenance. You should keep equipment manufacturers' maintenance and calibration instructions for all instruments for reference purposes. Field personnel must be familiar with the instructions provided by manufacturers. Contact manufacturers for answers to technical questions.

Each instrument should have a logbook for recording all maintenance and calibration information, including:

- serial number, date received, manufacturer's contact information, especially technical service representatives
- service records, dates of probe replacements
- maintenance records, for example, whenever the following general maintenance occurs: DO membrane replacement, pH reference probe junction and filling solution, probe cleanings, sonde (the sensor housing) replacement, impellor replacement or cleaning, etc.
- calibration dates and calibration data
- any problems with sensors
- pre-mobilization, post-calibration checks performed on individual sensor probes

After sampling all intervals of the vertical profile, compare the two first subsurface depth (0.5 or 1.0 m) measurements and confirm that they are within the accuracy specs of the sonde (e.g., within 0.2°C of the initial temperature reading and within 0.5 mg/L of the initial DO reading). If DO is found to be out of calibration, re-calibrate and re-record DO measurements. The purpose is to determine if the instrument held calibration during the profile. This will ensure that the field measurements for the day can be reported with confidence.

More extensive post-calibration procedures (beyond the first sub-surface depth check) are optional but encouraged if possible. The difference between the post-calibration values and expected standard values can be used to indicate both calibration precision and instrument performance. Table 4 contains suggested post-calibration error limits for DO, pH, and specific conductance (Elias et al. 2015). If values fall outside these limits, data collected do not meet QA standards and should be flagged appropriately (see SOP #12 in Elias et al. 2015). Measurements may be repeated with a different or back-up instrument. If post-calibration measurements do not consistently fall within the error limits after in-house trouble shooting, the instrument should be returned to the manufacturer for maintenance. The sooner the post-calibration procedures are performed, the more representative the results will be for assessing performance during the preceding field measurements. Calibration and post-calibration should be no more than 24 hours apart. When sampling daily, the second day's calibration can serve as the first day's post-field calibration check. Take the same care used in performing the initial calibration by rinsing the sensors and waiting for sensors to stabilize.

Table 3. Ideal calibration frequencies and acceptance criteria for field instruments for water temperature and DO (Elias et al. 2015, Table 9). The daily conductivity and pH calibrations are more than most RMN partners can do (and in some cases may exceed the manufacturers recommendation); based on feedback we've received from RMN partners, they tend to do weekly pH calibrations and monthly conductivity calibrations but follow the equipment manufacturers' calibration instructions.

Parameter	USEPA Method	Minimum Calibration Frequency and QC checks	Acceptance Criteria	Corrective Actions
Temperature	170.1	Annually, 2-point check with NIST thermometer	±1.0ºC	Re-test with a different thermometer; repeat measurement
Specific Conductance (SC25)	120.1	Daily, prior to field mobilization; calibration check prior to each round of sampling; 10% of the readings taken each day must be duplicated or a minimum of 1 reading if fewer than 10 samples are read.	±5% RPD 10%	Re-test; check low battery indicator; use a different meter; use different standards; repeat measurement
pH	150.1	Daily, prior to field mobilization (two buffers should be selected that bracket the anticipated pH of the water body to be sampled)	±0.05 pH unit	Re-test; check low battery indicator; use different standards; repeat measurement; don't move cords or cause friction/static
		Calibration check w/ third buffer prior to each round of sampling; check with low ionic strength buffer in addition, if conductivity is <50 µS/cm	±0.1 pH unit	
		10% of the readings taken each day must be duplicated or a minimum of 1 reading if fewer than 10 samples are read.	RPD 10%	
Dissolved Oxygen	360.1	Daily, prior to field mobilization; check at the field site if elevation or barometric pressure changed since calibration	0.2 mg/L concentration or ±10% saturation	Re-enter altitude; re-test; check low battery indicator; check membrane for wrinkles, tears or air bubbles; replace membrane; use a different meter; repeat measurement; allow more time for stabilization

Table 4. Post-calibration check error limits (Elias et al. 2015, Table 5).

Parameter	Value
Temperature	±1°C, annual calibration check
Specific Conductance	±5%
pH	±0.1 standard units
Dissolved Oxygen	±0.2 mg/L, ± 10% saturation

2.3 Equipment

This assumes you have access to a boat and anchor, a GPS unit for locating the sampling location and safety gear.

Multi-parameter meter. Instrument prices vary widely depending on which platform you select and which sensors you purchase. YSI and Hydrolab sondes, like those shown in Figure 7, are commonly used (but this is not an endorsement). The initial purchase price for a multi-parameter meter with temperature, DO, pH and conductivity sensors generally ranges from $10,000-$15,000 (Table 2). Some programs rent multi-parameter meters instead of purchasing them.

In addition to the cost of purchasing or renting the multi-parameter meter, plan for the following additional costs:

- Annual maintenance and repairs
    - Broken probes typically cost $500-$1000 to repair
- Calibration
    - Costs vary widely depending on frequency of use, the types of probes you are using, and whether you're purchasing calibration standards in bulk. Anticipate needing the following -
        - Temperature
            - National Institute of Standards and Technology (NIST)-certified thermometer
            - Calibration checks ($300/each)
        - DO
            - Barometer (for calibrations in the laboratory) ($200)
            - Deionizer (for making deionized water that is used for calibration) (optional; based on feedback we've received from RMN partners, tap water seems to work ok for DO calibration, but DI water should be used when calibrating other parameters and rinsing sampling gear between sites)
        - pH and conductivity
            - Need certificated calibration standards for each; estimated cost is around $25 per calibration (includes both parameters)

Table 5. Estimated costs to purchase a multi-parameter meter. This example is for the YSI EXO1 sonde, based on 2018 prices (this is not an endorsement; it is only an example). The cost and features of multi-parameter meters varies widely depending on which platform you select and which sensors you use.

Description	Estimated Costs
Sonde with 100-m depth, 4 sensor ports	$4,950
Conductivity/temperature sensor	$890
pH sensor	$560
Optical DO sensor	$1,960
10-m field cable	$610
Handheld display*	$2,700
Wheeled carrying case	$395
Total	**$12,065**

*with some sensors, it may be possible to skip the handheld display and use a tablet or laptop instead (but this raises potential challenges with exposure to the elements, such as rain, etc.)

Figure 2. Multi-parameter meters like the YSI and Hydrolab have three main components: the sonde (which the sensors are attached to), cable and handheld display.

Temperature only. If you do not have the resources to purchase a multi-parameter meter, but would like to take temperature profiles, one option used to be the AquaCal ClineFinder Temperature Sensor (Figure 3), but those have been discontinued. However other similar options likely exist. The accuracy of the sensor should be checked against a NIST-certified thermometer at the start of each sampling season (or more frequently if needed).

Figure 3. The AquaCal ClineFinder Temperature Sensor had been a low budget option for temperature profiles but has been discontinued. We are searching for possible replacements.

2.4 Field forms/records

Forms for recording RMN discrete vertical profile data should include:

- Lake name and site identification code
- Sample date, time
- GPS coordinates, to verify location
- Names of field team members
- Multi-parameter meter (model), calibration information
- Table for field measurements - depth, columns for each parameter, metalimnion (top/bottom)
- Any flags, notes or observations pertinent to the sample and/or sampling event
    - Whether any parameters were *not* collected, and reason
    - Weather (air temperature and wind speed) and relevant notes about recent weather (storms or drought)

An example field form (from EPA NLA 2017) can be found in Appendix A.

When handheld units are used to collect vertical profile data, much of this information is collected automatically (electronically). Electronic data should be backed up. If you are distrust technology and prefer paper, make sure someone QCs your electronic data after transcription.

Ensure that field forms, field notebooks, and other hardcopy records are secure, organized, and available for viewing, reproduction, or transfer upon request.

2.5 Data management

The goal is to upload the discrete vertical profile data to the Water Quality Portal/Water Quality Exchange (WQX), where it can be accessed by other regional partners.

There are three options for uploading profile data into WQX[3]:

- Option 1: Standard web-based application (WQX Web) that uses Microsoft Excel spreadsheets.
- Option 2: Create a custom submission application using WQX XML schema through Exchange Network Nodes or Node Clients
- Option 3: via a third-party system such as The Ambient Water Quality Monitoring System (AWQMS) or Lake Observer (https://www.lakeobserver.org/), which is free and accessible to the public. For more information, contact Lisa Borre (borrel@caryinstitute.org).

3 Low budget continuous sensor arrays

Most lake monitoring programs do not have the resources to purchase automated vertical profiling buoys/platforms, which can cost around $200K. However, there are more affordable design options, including instrument lines with sensors attached at fixed depths to a line that is vertically suspended below a buoy and attached to the lake bottom using an anchor system. The Minnesota Sentinel Lakes program has been deploying these types of arrays since 2008 and more and more state, tribal and federal programs are starting to follow suit. Costs of these arrays vary widely depending on what type of sensors you use and how many sensors you deploy. Most RMN partners are using temperature sensors that cost approximately $145 each and DO sensors that cost $1000-$1350 each. Other equipment needed for the arrays includes rope for the instrument line, floats/buoys, anchor(s) and zip ties. A detailed equipment list can be found in Section 3.4, as well as in the field protocols presentation in Attachment B.

At most RMN lakes, sensor arrays are deployed at the deep point in the lake. Efforts are made to keep the arrays as close to the same location as possible over time but we've come to realize that some amount of movement is unavoidable so we're just trying to minimize it. Year-round deployments are encouraged and have been successful at MN's Sentinel Lakes since 2008, but seasonal deployments during the ice-free season are also acceptable.

3.1 Array designs

There are many design possibilities. As an example, we are aware of at least four different buoy set-ups (one buoy on the surface; one buoy 1-meter below the surface; two buoys – one at the surface, the other 1-m below the surface; two buoys – both below the surface). The designs described in this document have all been tested and successfully used by various organizations for multiple years. Figures 4 & 5 show two design options that have worked well for RMN partners (and could be adapted/customized for your own lakes if needed). Advantages of the 'two buoy' design shown in Figure 4 (where one buoy is placed at the surface and the second buoy is placed roughly 1-m below the surface) include:

- The surface buoy is detachable (so that you can easily remove it during the winter if desired); tip: several RMN partners recommend using a snap shackle for the connector.
- If there are water level changes, the lower buoy helps prevent sagging in the instrument line (except in extreme situations).
- The lower buoy helps keep the instrument line straight when the wind blows.

[3] Instructions are available online: https://www.epa.gov/waterdata/water-quality-data-wqx.

- When deploying, it is easier to position and potentially make adjustments to the array (vs. with a surface buoy only, it can be a struggle – you may have to submerge the buoy or may end up with too much slack in the line).

A “grab” line like the one shown in Figure 4 is optional but encouraged to help with retrievals, especially in dark stained lakes.

A more recent evolution has been to run a second rope and buoy parallel to the instrument array and connect them with a rope. Each line has an anchor. MI DNR runs a rope between the two anchors to connect the two lines (Figures 6 & 7). When they retrieve the array to download data, they pull up the line without sensors first followed by the two anchors, which leaves no weight on the array line when they pull that in.

Of the designs described in this document, Figure 8 shows the lowest-cost design, which has been used in remote lakes in Maine (source: Julia Daly, University of Maine Farmington). This design utilizes cheaper temperature sensors (Onset HOBO Pendants, ~$75 per sensor, depending on memory) and buoys made from pool noodles. A bag filled with rocks serves as the anchor. They typically deploy three temperature sensors: one just below surface (which freezes into the ice in the winter and provides information on ice on and ice off), ~ 1m below the surface and ~ 1m above the bottom.

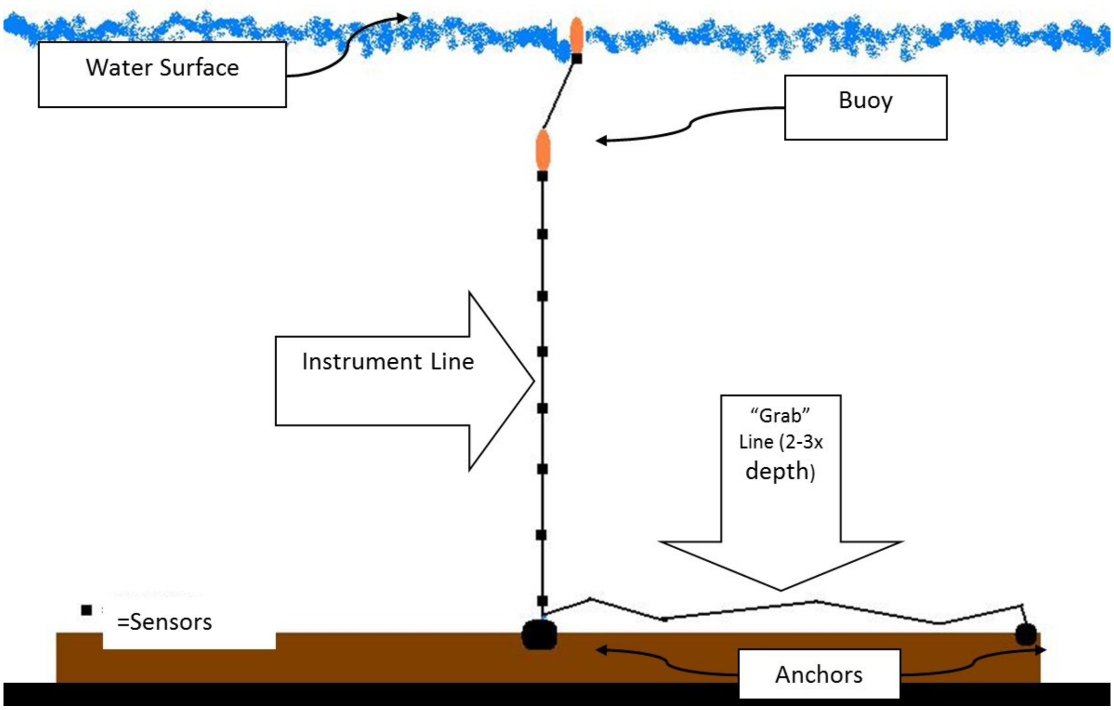


Figure 4. Schematic of a two-buoy moored sensor array with a “grab” line. This diagram was provided by the NPS Great Lakes Inventory and Monitoring Network (GLKN).

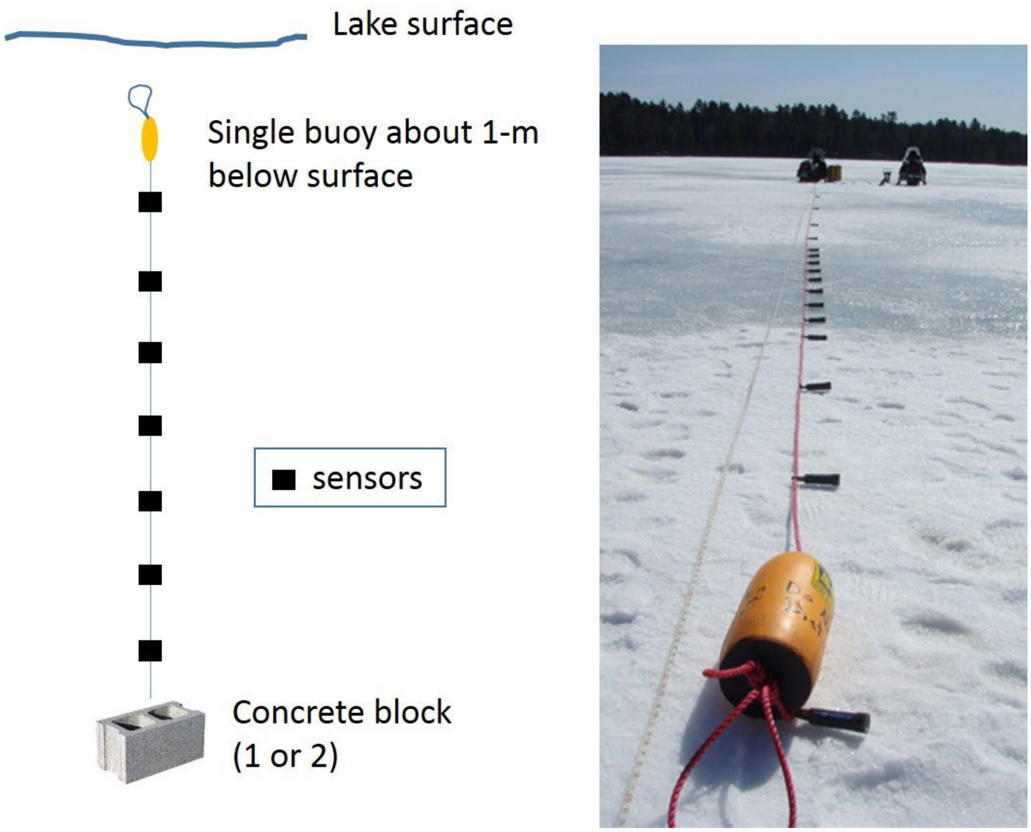


Figure 5. Schematic of a one-buoy moored temperature sensor array that has been used by the Minnesota DNR (MN DNR) at their sentinel lakes since 2008. The photo was provided by MN DNR.

Figure 6. Two-line design being used by MI DNR. Photo provided by Joe Nohner (MI DNR).

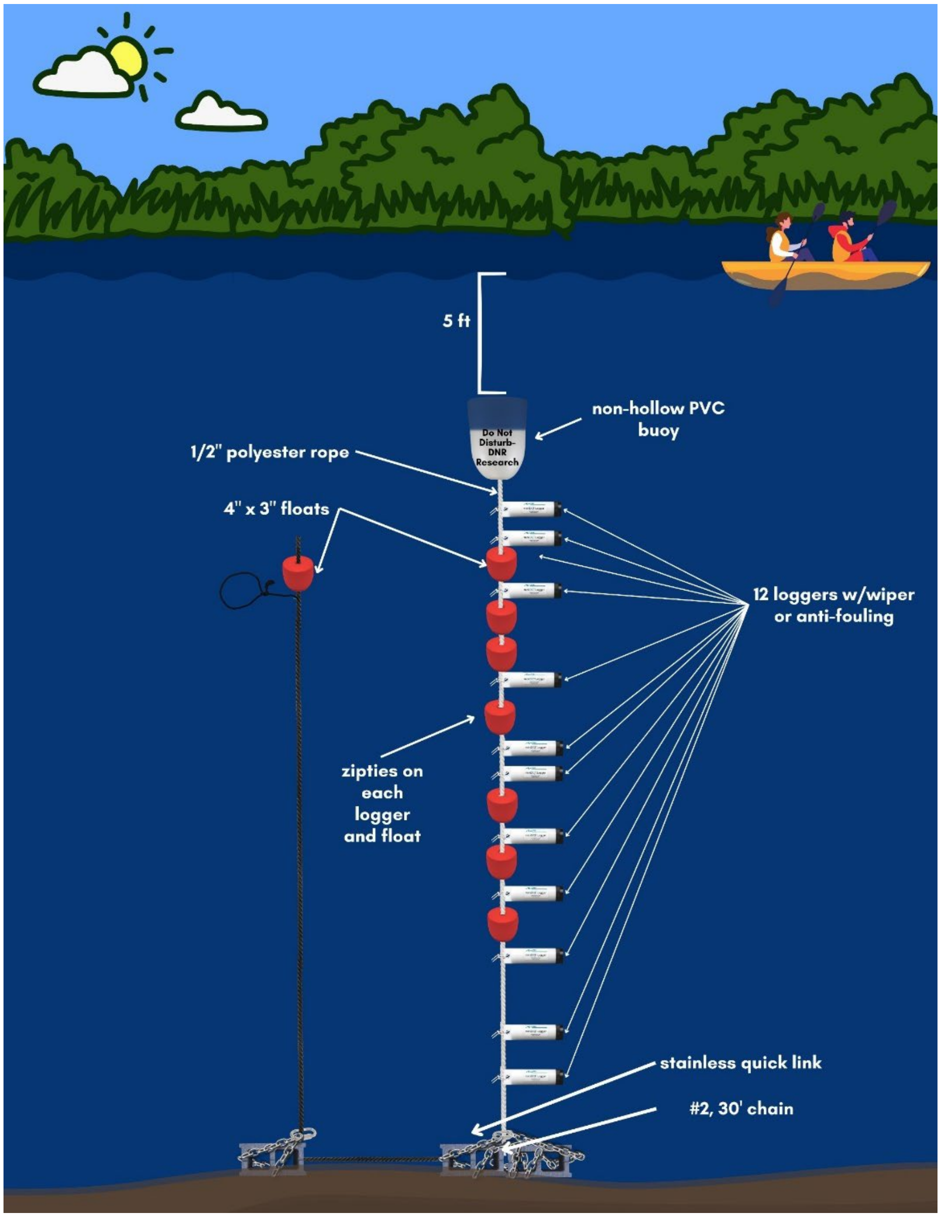


Figure 7. Two-line design being used by MI DNR. Image created by Sarah Nelson, Barry Conservation District, with assistance from Joe Nohner (MI DNR).

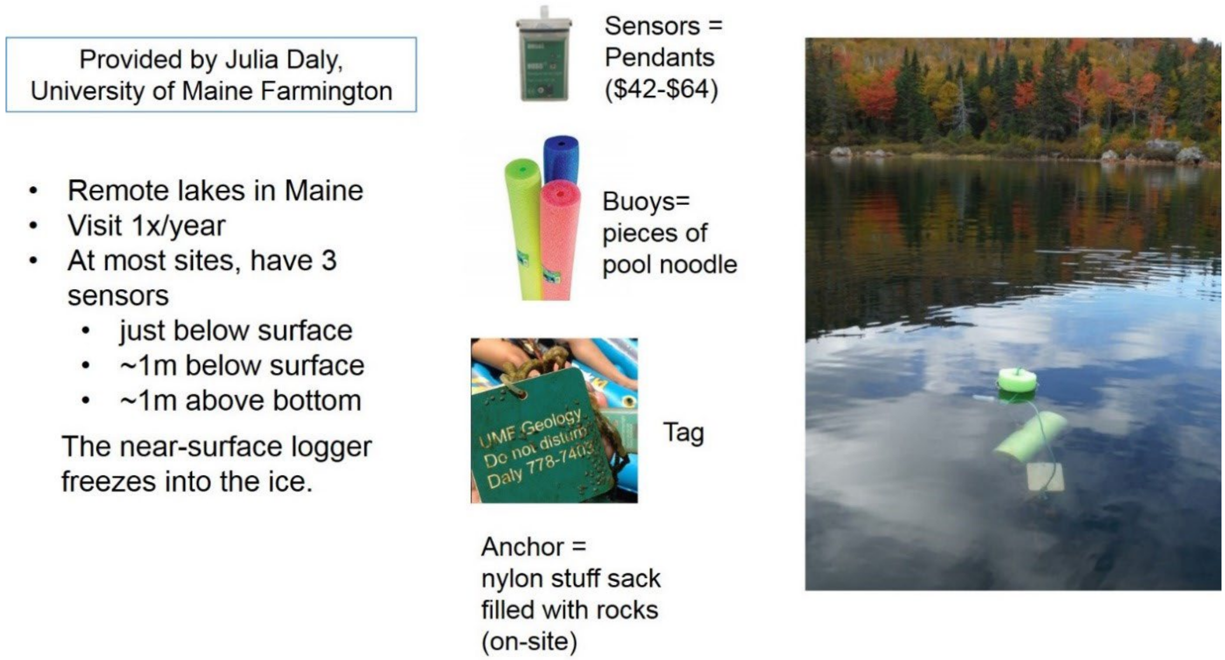


Figure 8. Lowest cost design, which is being used in remote lakes in Maine. The photos and protocols were provided by Julia Daly, University of Maine Farmington. Pendant sensor prices are now closer to $75 (12/28/2022).

3.2 Phases of implementation

If you deploy continuous sensor arrays, 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)

3.2.1 Pre-deployment preparations

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

- Site reconnaissance
- Pre-deployment sensor checks
- Label sensors
- Configure and launch sensors

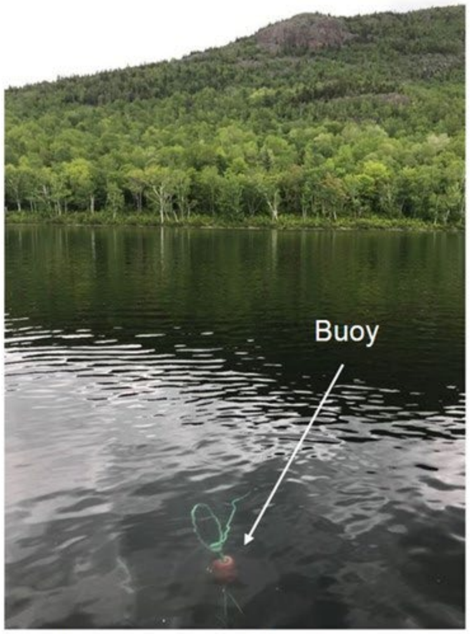
Site reconnaissance

The more you know about the lake and deployment site in advance, the better. Attachment C contains a site questionnaire that we encourage people to complete when considering candidate sites and array designs. The following information should be considered when designing your array -

- The **depth** of the location where you're planning to deploy the array. In stratified lakes, the depth affects how many sensors you put on the instrument line (see Table 6) and how heavy an anchor to use (longer instrument lines may be more prone to movement due to wind, so you may need a heavier weight).

- **Mixing pattern** – is the lake stratified? polymictic? (see Text Box #1 for explanations). If it is stratified, where is the thermocline typically located? This helps inform the number of sensors you will deploy and at what depths to deploy them (Table 6).
- **Boat traffic –** the more boat traffic, the higher the risk of vandalism and/or disturbance. This will influence how visible (or hidden) you make the buoy(s) (see Figure 9 for ideas on low and high visibility buoy designs) and how heavy an anchor to use (a heavier anchor may reduce the chance of a boat accidentally (or purposefully) catching and dragging the instrument line).
- **Rules and regulations –**
    - Some states require permits and potentially installation of navigation buoys with the sensor arrays. The permit process can take several weeks.
    - Some lakes do not allow sub-surface deployments. If you need to make the buoy highly visible, see Figure 9 for design ideas.
    - Are motorized boats allowed? This is important for the reasons mentioned above (risk of disturbance), as well as for deployment purposes (if you need to paddle in and out, a lighter anchor system would likely be easier to manage).
- **Accessibility** – what kind of boat can you use (is heavy and stable or light and tippy)? Is there a boat ramp? If there isn't a boat ramp and you need to haul everything in, this is important to consider when designing the anchor system.
- **Bottom substrate** – how well does the anchor take hold? How much does the anchor sink into the substrate? This will affect where you attach the bottom sensor (which should be ~1-meter above the bottom).
- **Water level fluctuations –** a two-buoy design (like the one shown in Figure 4) is recommended in lakes where water levels are known to drop (otherwise the instrument line may sag, which could cause some sensor depths to change and may cause burial of bottom sensor.
- **Prevailing wind speed and direction –** if the array will be deployed in an area that is exposed to high winds and large waves, consider using a heavier anchor and two-buoy design (Figure 4).

Low visibility



Single buoy design with the buoy positioned 0.5 to 1-m below the surface. Photo provided by Maine DEP.

High visibility

Highly visible surface buoys are required in WI lakes. Photo provided by WI DNR.

Surface buoy painted black to be less visually obtrusive. A second buoy is located ~1-m below the surface buoy. Photo provided by VT DEC.

Example of a high-visibility staff buoy that can be used in areas with motorboat traffic. Photo provided by NPS GLKN.

Figure 9. Examples of different buoy designs. Two low visibility options are shown on the left and two high visibility options are shown on the right. Which design is best will vary across lakes.

Text Box #1 – lake mixing pattern (stratified vs. polymictic)

Deep lakes that thermally stratify generally have three identifiable horizontal layers: the epilimnion (upper, warmer, wind-mixed layer), metalimnion (middle or transitional zone) and the hypolimnion (bottom, coldest, most dense layer). In lakes in northern temperate regions, a fairly common pattern is for the lake to 'turn over' (or mix throughout the water column) twice a year, during the spring and autumn. These are referred to as 'dimictic' lakes. During these mixing events, the lake is at the same temperature from the top to the bottom, versus the rest of the year, when temperature (and density) differences between upper and lower water layers are more pronounced, causing the formation of the three distinct horizontal layers. In contrast, polymictic lakes, which are typically shallow, do not thermally stratify and their waters mix from top to bottom throughout the ice-free period.

Pre-deployment sensor checks

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

Temperature sensor accuracy checks
Perform either single- or multi-point accuracy checks to verify that the sensors meet the accuracy quoted by the manufacturer. Compare the sensor readings to a National Institute of Standards and Technology (NIST)-calibrated thermometer; they should not exceed the accuracy quoted by the manufacturer (e.g., ±0.2°C if you are using the proV2 sensor). Figure 10 shows a commonly used single-point method called the "ice bucket" method. The sensors are placed in an ice bath for several hours and sensor readings are checked against readings from a NIST-certified thermometer. Sensors that have anomalous readings are set aside for further testing or returned to the manufacturer for replacement. If you are using Onset temperature sensors, placing them in a calibration bath at room temperature (vs. creating an ice bath) should be sufficient, as long as the bath is well-stirred and you have a good reference thermometer (Paul Gannett, Onset Product Line Manager, personal communication 7/6/2020). More detailed instructions for single- or multi-point checks can be found in the USEPA "Best Practices" report (USEPA 2014 - https://cfpub.epa.gov/ncea/risk/recordisplay.cfm?deid=280013).

Note: if you are checking the temperature sensors in Onset DO loggers in an ice bath, you may get a low battery alert (or in some cases, the sensor may stop logging) because the battery voltage goes down as the loggers get colder. We recommend that you check the batteries under load and under temperature conditions similar to those they will experience in the field, especially if you expect cold temperatures that may affect the battery as mentioned above. You can run a short deployment with the battery channel on to see where the voltage is (Paul Gannett, personal communication 7/6/2020).

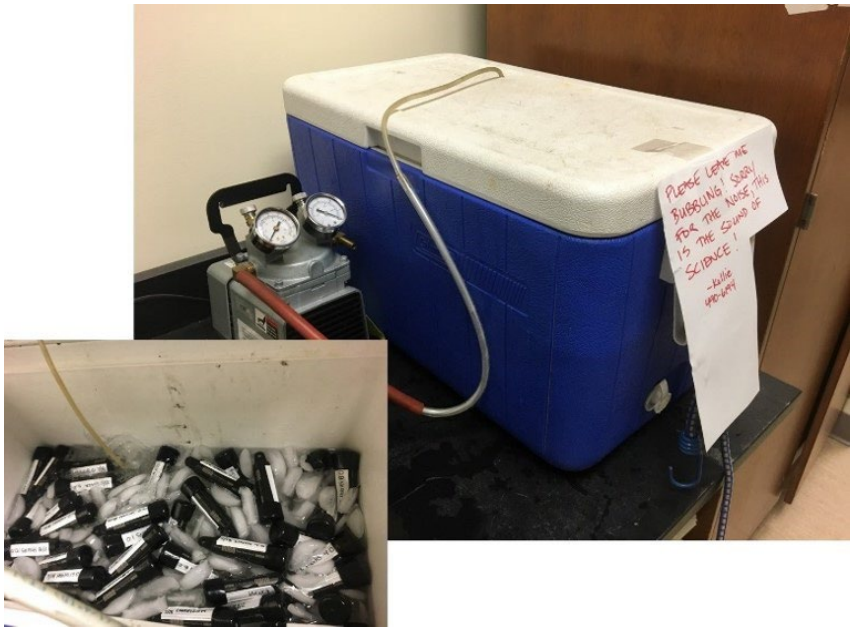


Figure 10. The "ice bucket" method is a commonly-used single-point method for checking accuracy of temperature sensors before deployment. The sensors are placed in an ice bath for several hours and sensor readings are checked against readings from a NIST-certified thermometer. Photos provided by VT DEC.

DO sensor calibration

Follow the manufacturer instructions to prepare the DO sensors for deployment. Instructions will vary depending on the sensor. At this time, the two DO sensors that are most commonly used at RMN lakes are the Onset HOBO DO sensor and the PME DO sensor.

If you are using the Onset HOBO DO sensor, it should be calibrated before initial deployment and after replacing sensor caps (which expire every 6 months with a 1-month grace period). To complete the two-point calibration (100% & 0%), you will need fresh water, the calibration boot and sponge supplied with the sensor, and a source for current barometric pressure at your location. The 100% calibration can be done with the calibration boot and wet sponge or in an air-saturated water bath, while the 0% calibration (which only needs to be performed if DO readings may be less than 4.0 mg/L or if you suspect anoxic conditions may be occurring at your site), can be done with a Sodium Sulfite solution, yeast (https://in-situ.com/wp-content/uploads/2015/01/RDO-Sensor-Two-Point-Dissolved-Oxygen-Calibration-Using-Yeast-Tech-Note.pdf) or another 0% oxygen environment.

If you are using the PME sensors, they come pre-calibrated/ready to be deployed but you can verify the calibration by performing two-point checks (for 0 and 100% saturation) in accordance with their instruction manual. PME recommends that the sensors be returned to them for recalibration every ½ million measurements.

Label sensors

If you are deploying multiple sensors at the same lake, we recommend taping a label with the following information onto the outside of the sensor cases: Site ID, depth and date of initial deployment (see example in Figure 11). These labels will make it easier to assemble the array and track the sensors over time.

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--10.0m_DO_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 website (https://nalms.shinyapps.io/ContDataQC/) and/or contact Jen.Stamp@tetratech.com.

If you choose to keep the S/N as the sensor name, that is fine as well. Whatever you decide, make sure you record the serial numbers and corresponding depths of sensors and keep this information in a safe place.

Figure 11. Putting labels on the outside of the sensor cases with lake name and sensor depth is optional but recommended.

Sensor launch and configuration

Temperature and DO sensors should be configured to record measurements at 60-minute intervals.
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 temperature, report in °C; DO, mg/L)
- 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 when you process the data.

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).

3.2.2 Initial deployment

After finishing the pre-deployment preparations, perform the following tasks:

- Assemble the array
- Navigate to the site
- Measure depth
- Make adjustments to the array if needed
- Take discrete vertical profile measurements (see Section 3)
- Deploy the array
- Document the site

Assemble the array

Most field crews assemble their array on land (see examples in Figure 12) and then transport it to the site, where they make adjustments if needed.

The basic components include:

- Continuous sensors
- Instrument line
- Grab line (optional but recommended)
- Float(s)
- Anchor(s)

Single-buoy system. Photo provided by MN DNR.

Two-buoy system. Photo provided by NH DES.

Figure 12. Example of two instrument line assemblies. Photos provided by Minnesota DNR and NH DES.

Continuous sensors

The number and spacing of sensors is driven by the lake mixing pattern (stratified vs. polymictic; see Text Box #1), depth of the lake and resource constraints.

Table 6 provides recommendations on spacing of sensors under different levels of effort (minimum to best) and Attachment D contains an array design worksheet. Temperature is the highest priority parameter (if you can only do one parameter, do temperature – the sensors are cheaper and require less maintenance). Most RMN partners are using temperature sensors that cost approximately $130 each. Figure 13 shows an example of recommended spacing of temperature sensors (if resources permit).

Due to the higher cost of the DO sensors ($1000-$1300 each), most RMN partners are only able to deploy one to two DO sensors (or none at all). DO sensor placement depends on the site, number of available sensors and objective. It is helpful to have discrete profile measurements to help inform sensor placement. If you are concerned about internal loading and have multiple DO sensors, we recommend concentrating the sensors in the hypolimnion, starting 1-m above the lowest sensor and working up in 1-m increments from there so that you can find the top of the anoxic zone. If you are more concerned about fish/oxythermal habitat, we recommend concentrating the loggers around the middle thermal layer boundaries, with the bottom logger around where you estimate DO to fall below a critical threshold (e.g., 3 or 4 mg/l).

If only one DO sensor is available, our default recommendation is to place it 1-m above the bottom as this is the area where hypoxia (oxygen-deficiency) is most likely to occur. If you are able to deploy a second DO sensor, we recommend positioning it ~1-m below the surface, which is often an oxygen-rich area and serves as a standard of comparison to the more oxygen-limited bottom layer. Once the baseline DO condition has been established, consider moving the DO sensor(s) to a different depth. For example, at several sites, the bottom 1-m consistently goes hypoxic for most of the year. In these situations, we're working with partners on strategies for moving the sensors (each is considered on a site-by-site basis).

The DO sensors measure temperature as well as DO. If you are using the Onset HOBO DO sensors, when the DO cap expires, the sensor stops measuring both temperature and DO. Thus, if you are unsure whether you can download the data before the DO sensor cap expires (every 6 months, with a 1-month grace period), we recommend deploying a temperature sensor alongside the HOBO DO sensor so that you don't lose risking temperature data for that depth.

Table 6. Recommended spacing of sensors under different levels of effort. Temperature is the highest priority parameter, followed by DO.

Mixing pattern	Parameter	Level of effort	Recommendations
Stratified	Temperature (highest priority)	Minimum	Two sensors: one positioned ~1-m below the surface and the other ~1-m above the bottom
		Best	In the epi- and metalimnion (top and middle layers, respectively), space the sensors 1-m apart. In the hypolimnion (bottom layer), space the sensors at geometrically increasing intervals (1, 2, 3, 4 then 5 m intervals to the bottom). See example in Figure 11
		In-between "minimum" and "best"	If you are able to obtain more than two temperature sensors but not enough to deploy sensors throughout the water column, position sensors ~1-m below the surface, ~1-m above the bottom and concentrate the others in the area where you think the thermocline is most likely to occur
	DO	Minimum	If one DO sensor can be obtained, position it ~1-m above the bottom, as this is the area where hypoxia (oxygen-deficiency) is most likely to occur; after several years, if a consistent baseline condition has been established (e.g., the site goes hypoxic most of the year), reevaluate sensor placement
		2 sensors	If you are able to deploy a second DO sensor, position it ~1-m below the surface, which is often an oxygen-rich area and serves as a standard of comparison to the more oxygen-limited bottom layer; after several years, if a consistent baseline condition has been established, reevaluate sensor placement
		> 2 sensors	If concerned about internal loading, place extra sensors in the hypolimnion, starting 1-m above the lowest sensor and working up in 1-m increments from there (to find the top of the anoxic zone). If concerned about fish/oxythermal habitat, concentrate the loggers around the middle thermal layer boundaries, with the bottom logger around where you estimate DO to fall below a critical threshold (e.g., 3 or 4 mg/l). Use discrete vertical profile data (if available) to help inform sensor placement.
Polymictic (year-round mixing)*	Temperature & DO	Minimum	One temperature and one DO sensor on one instrument line; ideally the sensors are positioned > 0.5 m off the bottom and >1 m below the surface
		Target	Two instrument lines, with one temperature and DO sensor per line, ideally positioned > 0.5 m off the bottom and >1 m below the surface. (explain dif'ce from dimictic

*Polymictic lakes are typically shallow and stay mixed throughout the ice-free season, thus fewer sensors are needed vs. deeper, stratified dimictic lakes

Carlos Temperature Sensor Chain

0		Epilimnion
1	Logger	Metalimnion (loggers placed at 1 meter intervals)
2		
3	Logger	
4		
5	Logger	
6		
7	Logger	
8		
9	Logger	
10		
11	Logger	
12		
13	Logger	
14		
15	Logger	
16		
17	Logger	
18		
19	Logger	
20		
21	Logger	
22		Hypolimnion (loggers placed at geometrically increasing intervals down to the bottom)
23	Logger	
24		
25		
26	Logger	
27		
28		
29		
30	Logger	
31		
32		
33		
34		
35	Logger	
36		
37		
38		
39		
40		
41	Logger	
42		
43		
44		
45		
46		
47		
48	Logger	

Figure 13. Schematic of the temperature sensor spacing on an instrument line in a stratified lake in Minnesota. This figure was provided by Minnesota DNR.

Instrument line

We recommend rope over cable or chains. This is because when you pull up the line to download sensor data, the cable is hard on the hands and it rusts if it is not stainless steel or coated. Moreover, if the instrument line gets tangled up in a boat propeller, cable and chains are more likely to cause damage than rope. Based on feedback from field crews, we recommend the following types and sizes of rope (Figure 14). Each have pros and cons:

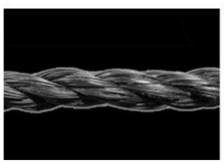
- 1/4” Solid braided polyester rope
    - Pros: very strong, lasts longest (typically 5 years or more), low stretch, good resistance to UV rays, if you use the Onset HOBO pro V2 loggers, the ¼” rope fits through the mounting holes
    - Cons: doesn’t float, not as easy to handle as the larger diameter rope, usually more expensive
- 1/2” Braided poly rope

    - Pros: floats, easy to handle, easy to attach sensors to (you can zip tie or weave parachute cord into the rope - see Figure 14), usually cheaper than polyester
    - Cons: likely to degrade faster due to ultraviolet (UV) rays (plan to replace it every 2 to 4 years), more likely to stretch than polyester rope
- 3/8" Pot warp (commonly used for lobster pots)
    - Pros: floats, easy to handle, easy to attach sensors to (you can zip tie or weave parachute cord into the rope - see Figure 15)
    - Cons: may have more resistance to UV rays, but as with poly rope, it will degrade faster than polyester (plan to replace it every 3 to 5 years), more likely to stretch than polyester rope

Tip: don't go smaller than the recommended diameters, as this will make the rope harder to handle.

1/4" Solid braided polyester rope

1/2" Braided poly rope



3/8" Pot warp

Figure 14. Examples of three types of rope that RMN crews have had success with.

Attaching sensors to the instrument line

There are several different ways to attach sensors to the instrument line. Which one is best will depend on the type of sensors and rope you are using. Techniques that people have had success with include:

- With poly rope or potwarp, you can run heavy-duty **zip ties** or **parachute chord** through the weave of the rope and connect them to the sensor (Figure 15). If you use zip ties, **use two and make sure they are heavy duty and UV resistant**. Check their condition each visit and change out as needed (they may get brittle over time, which has contributed to some sensors being lost when people pulled arrays over the gunnel of the boat)
    - Note: make sure you know where the sensor is located in relation to the mounting hole and do your best to position the sensor at the desired depth. For example, in the Onset HOBO DO sensor, the temperature and DO sensors are located at the end opposite the mounting hole, whereas with the Onset proV2, the temperature sensor is located next to the mounting hole.
- With the 1/4" solid braided polyester rope, if you use the Onset HOBO proV2 sensors, you can run the rope through the mounting hole (Figure 16). MN DNR does this and secures the sensors with heavy-duty zip ties above and below the sensors, supplemented with electrical tape. A downside to using this technique is that you may need to replace an individual sensor at some point (e.g., if one malfunctions); if it's located near the bottom of the instrument line, you'll have to remove all of the sensors above it to get to it.

- MN recently added PME DO sensors to their instrument lines. They are using two zip ties and electrical tape to attach them to 1/4" solid braided polyester rope (as shown in Figure 16).

We do not recommend using metal clips or caribiners to attach the sensors because: they tend to cut your hands when you pull up the line; it is difficult to find clips that will attach to the sensors (most are too big or too small); they tend to have corrosion problems.

Figure 15. With poly rope or potwarp, you can run heavy-duty zip ties or parachute chord through the weave of the rope and connect them to the sensor (Figure x). If you use zip ties, use two and make sure they are heavy duty and UV resistant.

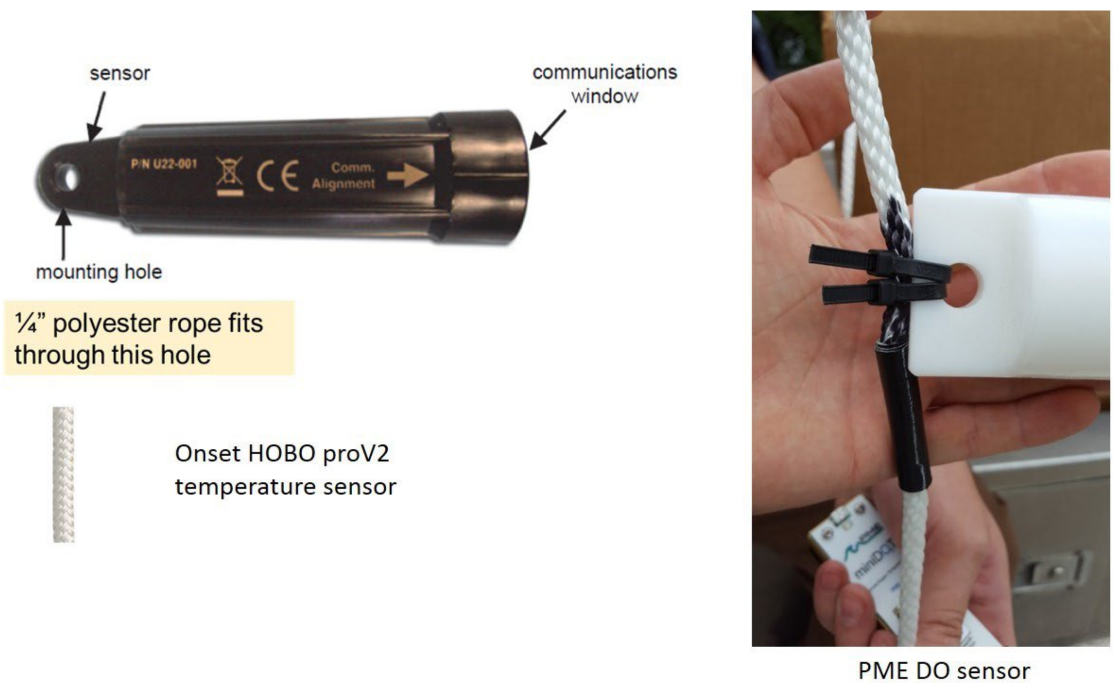


Figure 16. The 1/4" solid braided polyester rope fits through the mounting hold on the Onset HOBO proV2 sensor (left) and can be secured with heavy-duty zip ties above and below the sensors, supplemented with electrical tape. The PME DO sensors can be attached to the polyester rope using the technique shown on the right (photo from MN DNR).

Grab line

An example of a grab line is shown in Figure 4. It is optional but recommended. The same rope can be used for the instrument line and the grab line (meaning one line can be run throughout), or you can make them two separate lines (and tie off each one to the instrument line anchor). The grab line should be floating line (poly rope or potwarp). It should have enough buoyancy to float off the bottom enough to allow it to be snagged by a grappling hook. If you use non-floating rope (like polyester), consider adding a few small gillnet-type floats to give the line some buoyancy. Recommendations on the length of grab line vary. One crew uses 1.5 x the water depth as a rule of thumb; another uses 2-3 x the water depth. In deep lakes, limit the length of the grab line to something manageable (some crews limit it to 30-m (100-ft), others stop at 100-m).

Recovery loop

Above the top buoy, we recommend creating a 'recovery loop' (see examples in Figure 17). The loop makes the instrument line easier to grab during retrievals. The recovery loop can be made of either floating or non-floating line (your discretion). Do not skimp on the length of it! Make the loop big enough to easily grab. You may even consider having two loops.

Figure 17. Examples of recovery loops. Bigger is often better!

Floats/buoys

We recommend that the primary float(s)[4] on the instrument line should be closed cell, not hollow plastic. A commonly-used size is 6”diameter by 14” but there are many options (such as the pool noodles shown in Figure 8; other types being used are shown in Figures 9 and 12).

We recommend clearly marking/labelling the top buoy (e.g., write “Do Not Disturb, Research Buoy” as well as your contact information).

If you have two buoys (surface and subsurface), when assembling the array, leave about 1-m slack between them (for example, have about 2-m length of rope between a sub-surface buoy that is to be deployed 1-m under the water and the surface buoy). If you plan to remove the surface buoy during the ice-on season, attach the surface buoy in a way that it can easily be removed (see NH DES photo on the right in Figure 12).

In addition to the primary floats, sometimes crews put some small gillnet-type floats on the instrument line (e.g., between sensors) and/or on the grab line. If you are using polyester (non-floating) rope and have a heavy anchor (concrete blocks), this should work fine but if you are using floating line and a relatively light anchor (<20 lbs), beware - these extra floats have created problems for some crews because the lines become too buoyant and they are unable to submerge the instrument line. If it is your first deployment and you are not sure how buoyant your line will be, we recommend doing some test runs beforehand (e.g., in a 55-gallon barrel, or in the shallow part of the lake) to determine appropriate anchor weight needed to submerge buoys. We recommend bringing an extra anchor and/or additional weight in the field.

Anchors

There are many different options for anchors, including mushroom and Danforth anchors, concrete block(s) (full or half; one 8 x 8 x 16 concrete block weighs approximately 35 lbs.), homemade concrete anchors with bent rebar, and nylon mussel gathering bags filled with rocks gathered on-site. One partner recently innovated a new design using steel plates (Figure 18).

Considerations when deciding upon a weight for the anchor include:

- What type of boat will you be using? Working from a stable, spacious motor boat with a winch is much different than working from a canoe or inflatable kayak.
- How heavy a weight can you lift? If you’ll be pulling up the sensor array by hand, make sure it is something you can reasonably lift without capsizing the boat or causing injury to persons working on the array.
- Is it a remote lake that you have to hike into? If so, consider using nylon mussel gathering bags filled with rocks gathered on-site.
- What type of rope are you using? If using floating rope (poly or potswarp), you will need more weight (probably 25 or more lbs)
- How long is your instrument line? The longer the line, the heavier the weight you will likely need.

[4] By primary, we mean the one that stays on year-round. If you have two and remove the surface buoy during the winter, the primary is the subsurface buoy. If you have a single buoy, that is the primary.

- Do you only have a surface buoy? If so, your line may be more prone to movement due to wind, so you'll likely need a heavier weight
- How much boat activity is there? The biggest danger may be from people accidentally (or purposefully) catching and dragging the line. In busy areas, you may want to use a heavier weight to make the array harder to drag.

When purchasing a buoy, try to find out its buoyancy and plan accordingly (e.g., a 6" x 14" closed cell buoy provides ~10 lbs (170 ounces) of buoyancy, so a good initial target weight for the instrument line anchor is 15 lbs. (or more, if pulling up additional weight is not a concern).

If you have a grab line in addition to the instrument line, the grab line should have its own anchor (see schematic in Figure 4), and the grab line anchor should weigh less than the instrument line anchor.

There are many different techniques for attaching the instrument lines to the anchors. Use your best judgment as to which is best for your array. If you are using concrete blocks for anchors, they are abrasive, so we don't recommend tying the rope directly around them (instead consider putting rubber hose around the rope or using chains or cables that you then tie the rope around). If you do tie directly to the concrete, watch carefully for wear over time.

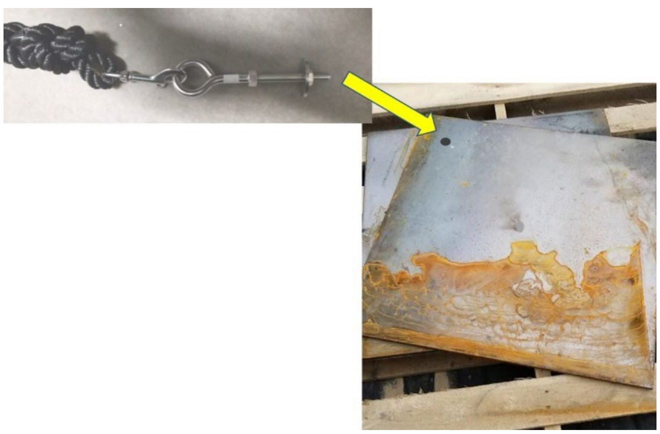


Figure 18. One partner recently started using anchors made of steel plates, which are connected to the instrument line via an eye bolt. For more information, contact Shane Bowe (shane.bowe.redlake@gmail.com).

Navigate to the site

Navigate to the deployment site and position the boat in the desired location. Do your best to keep the boat in position without drifting. If you have a boat with a motor and its own anchor(s), it is best to stop the engine and set the anchor(s). However, we understand that stopping your motor may not always be possible (e.g., in bad weather or with a balky engine). If you need to keep the motor running to stay in position, avoid sampling water showing evidence of oil, gasoline or anything else from the boat.

If you don't have a motor or an anchor, some people use the grab line anchor to stay in position (see Text Box #2 for a description of a technique that the NPS GLKN crews have had success with).

TEXT BOX #2 – Technique for positioning a non-motorized boat with a grab line (source: Damstra and VanderMeulen 2017)

If you are in a canoe or kayak without an anchor and are deploying a two-buoy array with a grab line, this sequence has worked well for NPS GLKN crews. You use the grab line (and its anchor) to hold the boat in position when taking measurements and deploying the instrument line.

- **Grab line deployment**. Position the boat upwind (how far upwind depends on the lake depth/length of the instrument line). The goal is to drift to the location where you want to lower the instrument line, taking out slack in the grab line while doing so, otherwise the grab line may get bunched up and float to the surface). While maintaining the boat in a set position, drop the grab line anchor straight down in a controlled manner. **Collect a GPS point immediately after the anchor hits the bottom.** Next, drift, motor, or paddle downwind a few meters—maintaining tension on the grab line but without dragging the anchor—until the whole grab line is in the water. At this point the grab line will be on an angle from the lake bottom to the surface because you have not yet begun to lower the instrument line.
- **Instrument line deployment**. Once in position, lower the anchor attached to the instrument line. As you do so, consider paddling or drifting very slowly to ensure that most of the slack is taken out of the grab line by the time the anchor hits the bottom. Otherwise, especially for long instrument lines, the grab line may have too much slack, float upwards in a hump, and be difficult to grab with the grappling hook when retrieving the array or allow the line to float to the surface. Once the sub-surface buoy goes under (this is a two-buoy design), carefully lower the rest down, being sure to notice when the anchor hits bottom. Ideally, once the anchor is at rest, you should be able to hold onto the surface buoy a half meter or so above the surface of the water (About 1 m is the ideal amount of slack between the surface (black) buoy and the sub-surface buoy (under the water, with anchor resting on the bottom). **Immediately collect a GPS point on a GPS unit** and record on a field sheet.

Measure depth

It is very important to get an accurate depth measurement prior to deployment, as this will be used to make final adjustments to the fixed sensor array (as needed). For better accuracy, we recommend taking the measurement with a line that hangs vertically and touches the bottom (vs. relying on sonar depth finders or bathymetric maps). Techniques include using a multi-parameter meter on a cable; a measuring tape attached to the same anchor that is being used for the instrument line (which will also give you a feel for how much the anchor is likely to sink in the bottom substrates); or attaching a brass chain or a plumb line to a measuring tape.

Use this depth measurement to verify that the correct location is being sampled and to adjust sensor depths on the fixed array as needed.

Take discrete vertical profile measurements

Take discrete vertical profile measurements (described in Section 2) during each site visit (if possible). Try to take the measurements as close to where you'll be deploying the instrument line as possible. If you have a two-person crew and one person is deploying the array while the other takes the vertical profile measurements, be careful about disturbing the bottom sediments with the anchor of the instrument line in the area where you are taking water quality measurements.

During the initial deployment, the profile measurements cannot be used for sensor accuracy checks because the sensors will not have had time to stabilize. However, we still encourage collection of the profile measurements during your first visit.

TEXT BOX #3 – Techniques for improving alignment of discrete vertical profile measurements with sensors

Two types of techniques are currently being piloted to help field crews better align their discrete profile measurements with sensors. This is particularly important for measurements being taken in the metalimnion, where temperatures change by >1°C.

The simplest (most recommended) technique involves taking discrete measurements at more depths, at least in the thermocline (e.g., every 0.25 or 0.5 meters in the thermocline instead of every 1-meter). While this doesn't help field crews align the probe with the sensors, it provides more discrete measurements that can be compared to the sensor measurements. If none fall within the sensor accuracy requirements, this will be cause for concern.

A second technique that the Red Lake Band of Chippewa Indians is piloting involves 'calibrating' the line between the top buoy and second buoy by marking it at a known distance from the top sensor. Measuring from the marks to the water's surface will provide an appropriate correction to match sensor depth. For example, if the water's surface is 0.54 m from the 1-m mark, the first sensor is at 0.46 m depth (1 - 0.54 = 0.46). This would mean that the first discrete sample taken during profiling visits would be taken at 0.46m, the second at 1.46 m, and so on. Sondes with depth sensors should be carefully calibrated to ensure depth is correctly displayed on the sensor. If a sonde without a depth sensor is used a meter stick can be used to match 1 m markings on the cable.

Deploy sensor array

Techniques for deploying the arrays vary depending on many factors, including the design you use and the platform you're working off. Field crews deploy the arrays from all kinds of boats, ranging from stable motorized skiffs with anchors and lots of space, to non-motorized, lightweight, less stable boats like canoes[5] or inflatable kayaks with very little working space (Figure 19). Thus, we cannot provide universal procedures, but we can recommend some general rules of thumb -

- When you load up the boat, it is important to be well-organized (see example in Figure 20), especially if you will be deploying the array from a small working platform.
- Be aware of the temperature differential between the sensors and the water that they are being deployed into. If it's a hot day and the sensors are sitting in the sun before being lowered into cold water, sometimes they stop working due to the abrupt temperature change ('shock cooling'). If this is a concern, when you load up the boat, try to keep the sensors in the shade or in a cooler to minimize the temperature differential.
- If you are using floating line, bring an extra anchor and/or additional weight. During initial deployments, some field crews have found their lines to be too buoyant.

[5] If using a canoe, we recommend that you use stabilizers to prevent capsizing.

- Before deploying the lines, make sure anchors are attached to the appropriate lines (instrument or grab) and make sure all persons and equipment are clear.
- While maintaining the boat in a set position, lower the anchors down slowly in a controlled manner (do not throw them!). When you lower the instrument line, be careful not to hit the sensors on the side of the boat as the line goes out.
- **For both the grab line and instrument line anchors, record a GPS point for each one immediately after the anchors hit the bottom.**
- Evaluate and make adjustments if needed
    - Is the instrument line too long? Too short? Too buoyant?
    - Is the upper-most instrument below the surface or at or near the depth you have assigned to it?
- Note the time when the instrument line and sensors are in position. This is important to know because you may need to trim/remove the first several sensor measurements while the sensors are still stabilizing.

If you are deploying an array with a grab line from a canoe, Text Box #2 provides tips from NPS GLKN.

Figure 19. Field crews deploy the arrays from all kinds of boats, ranging from motorized skiffs to canoes to inflatable kayaks.

Figure 20. It is important to be well-organized, especially if you will be deploying the array from a small boat. This example is from Amy Smagula, NH DES.

Document the array

It is critical to document the location of the array 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 arrays, we recommend that you -

- Record GPS coordinates (latitude and longitude) for the exact site at which each array is deployed, as well as the datum of the GPS. If you are unable to obtain GPS coordinates in the field, note the sensor location on a map and determine the coordinates later.
- Make notes about and photograph landmarks that could help you locate and retrieve the array, especially if this is an initial deployment. Without a GPS, landmarks may be used to locate the array, but this will likely increase the time needed to locate the array
- Use a grab line. Record GPS coordinates for both the grab line anchor and instrument line anchor.
- Take photographs from different perspectives. Photographs are useful for relocating the array as well as documenting any changes to the monitoring location over time. Include at least one shot with a visual marker (e.g., someone pointing to the array). Later, when viewing these photos on a computer, annotate them with notes about landmark references (e.g., unique rock along the shoreline), boat launch, paths to the lake, and whatever else might be appropriate.

We also recommend that you draw a schematic of the array like the one shown in Figure 21 (which shows how many sensors are on the line, how they are positioned, and sensor type). If you make adjustments to the array over time (e.g., lengthening or shortening lines, adding another sensor), be sure to update the drawing accordingly.

Keep a document for each array that has all the sensor serial numbers, depths, and GPS coordinates. On your computer, store the information in the folder or subfolder where you are putting your raw sensor data. Or if somewhere else, ensure that the location can be identified by someone other than you. Consider documenting file locations in your QAPP.

In addition, we recommend that you include your contact information on the array, whether it be in the form of a research tag (see example in Figure 8) or by writing it on the buoy (see example in Figure 9). If your agency has specific policies regarding signage, follow those protocols.

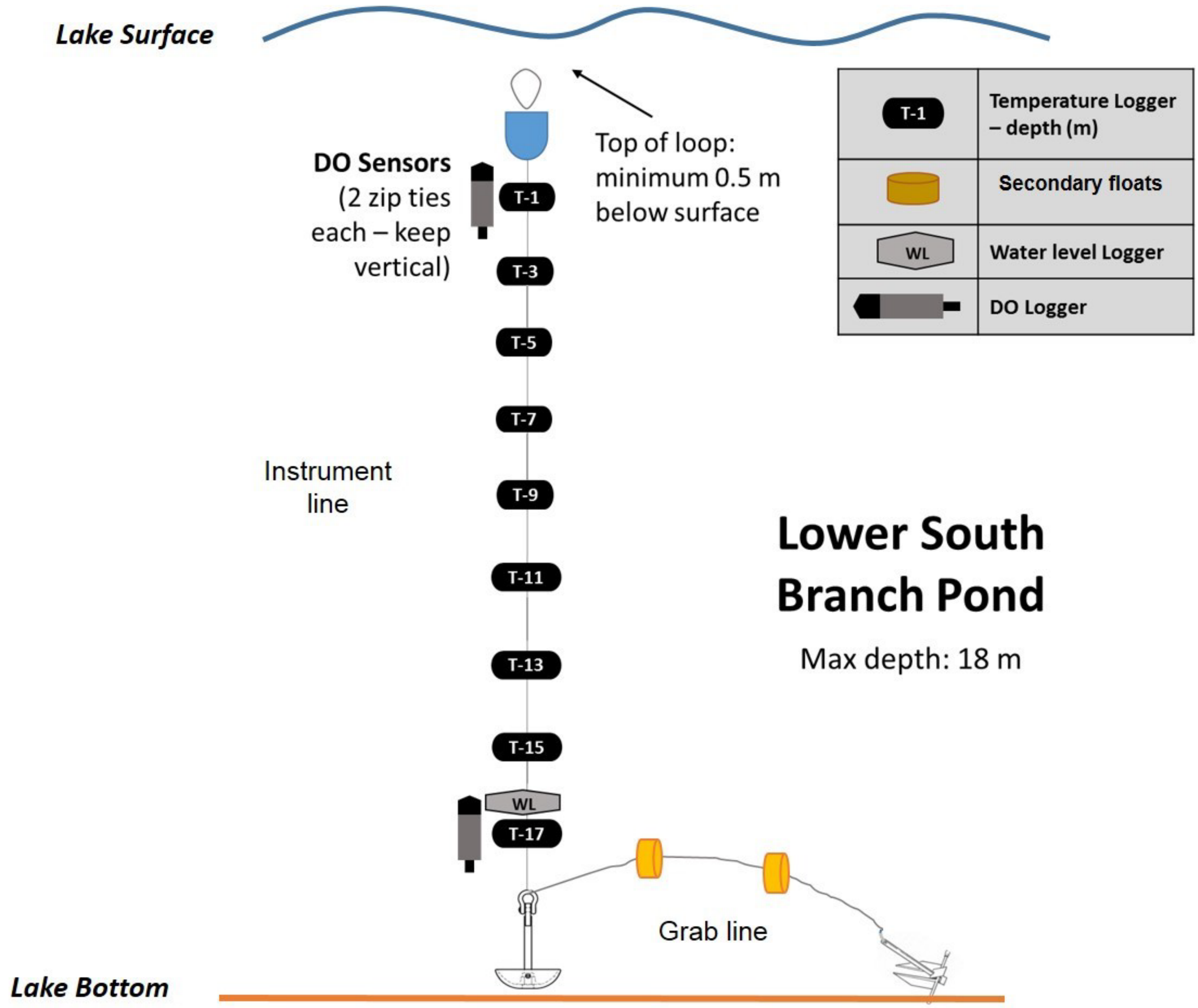


Figure 21. Schematic of a single buoy array. It shows how many sensors are on the line, what depths they are at, and what types of sensors are deployed. This diagram has been slightly modified versions that were originally provided by Shane Bowe (Red Lake Band) and Jeremy Deeds (Maine DEP).

3.2.3 Follow-up visits

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

- Prepare download devices
- Locate/navigate to the array
- Measure depth
- Take discrete vertical profile measurements (see Section 2.1)
- Pull in array/download sensor data/perform maintenance as needed/redeploy the array in the same location
- Document/complete field forms

After doing the initial deployment, there is flexibility in the timing of follow-up visits, especially if you are only collecting temperature data. At a minimum, temperature data should be downloaded once a year. 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/loss of data and causing movement of sensor arrays (each time the array is removed to download data and returned to position, sensor depths shift slightly, which is reflected in the water level data).

If you are deploying the HOBO DO sensors year-round, the sensor caps need to be replaced every 6 months (when the cap expires, the sensor stops logging both DO and temperature). If you are debating deploying the HOBO DO sensors during the open water season vs. year-round, it may be helpful to take a discrete winter DO profile; if DO concentrations appear stable and are not close to thresholds for aquatic life, seasonal DO measurements during the open water season could suffice (depending on your objectives).

If you are in a location where the lake freezes over during the winter, some field crews prefer to work on the ice vs. open water. As with everything, there are advantages and disadvantages. A disadvantage is that it can be more challenging to find the sensor array through the ice. An advantage is that it may be easier to work on top of the ice, especially if you have access to a heated pop-up shelter, versus fighting wind and waves on the open water in late October. This assumes common sense prevails and you stay off thin ice!

Prepare equipment

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

Bring extra sensors (if available) in case you need to replace any. Some entities have enough sensors to change out the entire array (meaning they pull up the array that had been in the water and replace it with a new one). That is fine if you have sufficient numbers of sensors to do this and if you carefully document the change-out.

Locate the array

Finding the array can be challenging, particularly in dark-stained lakes with subsurface buoys. Here are some recommendations from field crews based on their experiences -

- Before going to the lake, review photos and maps from the initial documentation.
- If you have a grab line and took GPS coordinates of the grab line anchor and instrument line anchor, create a waypoint between the previously collected GPS points for the end of the grab line and the instrument line (this can be done in ArcMap or another mapping program such as Google Earth). Be sure to load this point into the GPS unit before leaving the office.
- Navigate to the most recent coordinates for the array using a GPS unit (the higher the accuracy, the better). If that doesn't work, try navigating to the waypoint described above.

- If it is the open water season and you can't find the array with the GPS unit, try using a grappling hook. Here are tips from NPS GLKN on using a grapple hook to retrieve an array that has a grab line -
    - Use a grappling hook that is made of strong steel.
    - Make sure you have enough line (1.5×–3× the water depth) and weight on the line to keep the hook in constant contact with the bottom.
    - Consider attaching one end of the line to the boat to ensure that the line is not lost.
    - Go slowly to ensure that the hook stays in contact with the bottom while 'trolling'. If you are not sure if you are dragging the bottom, or if you feel the rope "thrumming" when you touch it with your hand, you may not be on bottom. The "thrumming" is the hook vibrating in the water column.
    - Try dragging the hook perpendicular to where you believe the grab line should be. If this does not work, try making several wide circles around the point.
    - If you are successful at hooking the array, it is advisable to only lift with the grappling hook line until the buoy reaches the surface of the water; then grab the line at the buoy and continue lifting the instrument line.
- If you do retrievals on ice during the winter, MN DNR has had success with the following technique: first locate the array (or where you think the array should be) with the GPS, then drill a hole in the ice. Then take a look with an underwater camera and fine tune the hole as needed.
- Other techniques that people have tried using to find lost arrays include:
    - Side scan sonar
    - Drones (aerial or submersible)
    - Recruiting volunteers from the local dive club

Measure depth and take vertical profile measurements

After you locate the array, move your boat into the desired position and do what it takes to keep it there (in some cases, people have anchors on their boats that they can drop; if you don't have a boat anchor but have a grab line, some people raise the instrument line and then use the grab line anchor to keep them in position).

The protocols for taking the depth and vertical profile measurements are the same as the ones used during the initial deployment (see Sections 4.1.2.3 and 4.1.2.4). To get the most accurate depth measurement, we recommend taking it with a line that hangs vertically and touches the bottom, such as a multi-parameter meter on a cable, or a measuring tape attached to a brass chain or a plumb line.

For the discrete vertical profile measurements, take them before you download the sensor data, in as close proximity as you can to the instrument line and as close to the sensor depths as you can (estimate as best as you can; you won't be able to know for sure without diving into the water or using an underwater camera to confirm). Also take the measurements as close to the top of the hour as you can (assuming you set the sensors to record every 60 minutes, at the top of the hour). These discrete measurements will be compared to the closest measurements from the sensors and used for accuracy checks.

Retrieve array, download data, perform maintenance if needed

After you locate the array and position the boat in the desired location, pull the instrument line into the boat. People have different techniques for doing this (for example, to keep it more manageable, some flake (coil) the line into a storage tub). As you pull up the line, be careful not to damage the sensors by hitting them on the side of the boat. Also consider putting some form of cushioning on the gunnel (one crew had a sensor break lose as they were pulling it over the top rail). Also beware of fishing hooks - some field crews have encountered them when pulling up instrument lines; as a precaution, we recommend that field crews wear gloves, pants and other protective clothing.

When you pull up the line, be sure to write down the time the sensors are out of the water (this is important to know for data QA/QC).

Some entities have enough sensors to put together a second array. In these situations, they pull up the array that had been in the water, replace it with the new one, and bring the old one back to the lab where they download the sensor data. But most people aren't in this position and need to redeploy the existing array after downloading the sensor data in the field.

If you download the sensor data in the field, follow the manufacturer's instructions and use the appropriate device(s). If you are using Onset HOBO sensors, instructional materials on downloading data are available upon request (email Jen.Stamp@tetratech.com). The HOBO waterproof shuttle is easier to work with in the field than the base station (which is not waterproof and requires a laptop with HOBOWare software). A downside of the HOBO waterproof shuttle is that you won't be able to view battery life or the data files until after they've been transferred from the shuttle to a computer with HOBOWare. Also, the shuttle needs to be shaded during the download (it uses infrared light to transfer data and may not work properly if it's in direct sunlight).

As you're working with the array, perform the following checklist -

- *Instrument line* – check the condition of the rope. Replace if needed (it degrades over time due to UV. It may also stretch, which affects the position of the sensors).
- *Sensors* –
  - Check for any signs of fouling, disturbance, or vandalism. Clean if needed.
  - Check battery life (if able); replace batteries if needed
  - Replace the DO sensor cap if needed; perform field calibration if needed (see Text Box #3)
- *Buoys, anchors* - check their condition. Replace if needed.

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 (60-minutes, at the top of the hour). Also, clear/format the sensor memory to free up space and prevent carry-over of the previously recorded data. If you are using the Onset HOBOWare waterproof shuttle, after the download, it automatically clears the sensor memory and relaunches the sensor, carrying over the same configuration settings that had been previously used.

Throughout this process, take careful notes. Photos may be helpful for documentation as well. If you see anything that could affect the accuracy of the measurements, make a note about it on the field form (e.g., was the array where you expected to find it or were there signs of movement? any signs of fouling, disturbance or vandalism?).

Also, during each visit (even if you're not downloading sensor data), clean off algae on the upper buoy and recovery loop. The algae can grow quickly and weighs down the sensor array (in some cases, causing it to partially sink). This can happen at even relatively pristine sites, like the example in Figure 22.

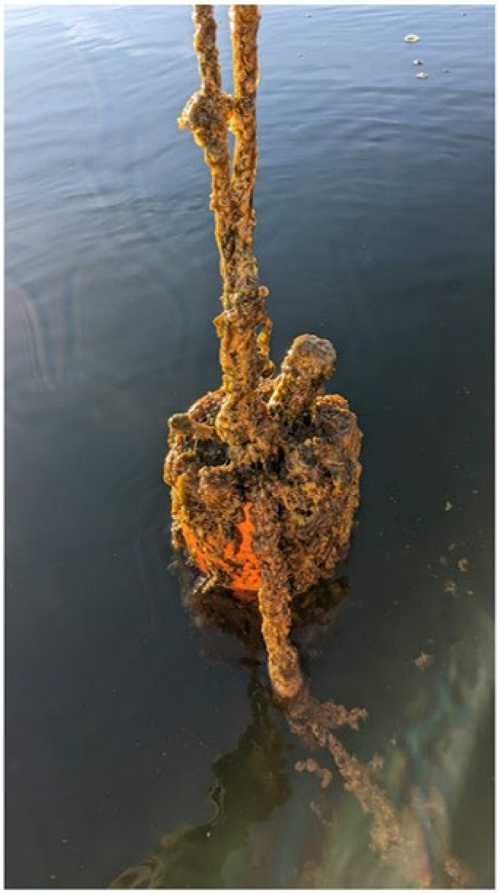


Figure 22. Algal growth on the buoy and instrument line at a relatively pristine lake. Photo provided by Shane Bowe, Red Lake Band.

Redeploy the array

Once the data download is complete, put the array back into the same location as before (or as close as you can get it).

TEXT BOX # 4 – Calibration of Onset HOBO DO sensors

The Onset HOBO DO sensors need to be calibrated during their initial deployment and after sensor caps are replaced. The manufacturer provides instructions on how to perform the calibration, which can either be done in the laboratory or the field. It is easier to do the calibrations in the lab vs. the field but several field crews have done the 100% saturation calibrations in the field after changing out the DO sensor caps.

Lab Calibration - recommended after new DO sensor cap is installed
-100% calibration with included calibration boot or in an air-saturated water bath; barometric pressure reading required (which can be obtained from some multi-probe meters, nearby weather stations, a barometer app that you can get for iPhones, or, in some cases, on-site pressure transducers).
-0% calibration recommended if DO readings may be less than 4.0 mg/L. RMN partners have had success with the yeast method (which is cheaper and safer than the traditional method, which involves using sodium sulfite).

Field Calibration –use to compensate for fouling or to calibrate data instead of lab calibration.
-Take precise readings at the start and end of each deployment –after stabilization
-Use both start & end points to compensate for fouling.
-A single-point calibration can be done with a reading from any time within the deployment.
-Field Meter/Sonde (Recommended) – fastest method at around 5 minutes and logger can remain in the water
-100% saturation method (less preferred) –useful if a field meter is not available
Use Calibration Boot with freshwater for sponge.
Allow time for air in boot to reach saturation and for logger to reach temperature equilibrium with surrounding air (time depends on temperature difference from where it was)
Requires barometric pressure

3.3 Quality Assurance/Quality Control (QA/QC)

QA/QC is a critical component of monitoring, as it ensures data quality objectives are being met. At RMN lakes, oversight and compliance with the following QA/QC procedures is left up to participants.

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

- Perform pre-deployment accuracy checks on the temperature sensors (see Section 3.1.2; more detailed procedures can be found in USEPA 2014)
- Calibrate the DO sensors in accordance with manufacturer instructions at recommended intervals (see Section 3.1.2 and Text Box #3)
- During each site visit, take depth measurements and discrete vertical profile measurements with a calibrated meter, using the following procedures to the best of your ability:
    - Take the measurement in as close proximity as possible to the sensors and as close as possible to the time when the sensors are recording measurements (every 60 minutes, top of the hour).

- Ensure that sufficient time has passed to allow the meter to stabilize before recording the measurement.
- Note on the field form whether the time of your measurement is standard or daylight savings time.
- When you view the sensor data at a later time, compare the measurements (see example in Table 7).

The discrete measurements are expected to be within the accuracy range of the sensor (e.g., with HOBO ProV2s, the measurements should be within ±0.2°C). This type of check makes the data more defensible and can potentially be used to make corrections. However, in lakes, the sensor accuracy checks are difficult because field crews do them below the surface 'in the blind', meaning they cannot see how close the multi-probe meter is to the sensors. At the upper and lower depths, this does not make a big difference, but around the thermocline (where temperatures change by >1°C, it can, as shown in Table 7). Despite this limitation, we still recommend that the discrete vertical profile measurements be collected and compared to the sensor measurements and continue to pilot new techniques (see Text Box # 3) to try and address this issue.

Another important component of lake RMN QA/QC is documentation. This includes keeping records of the calibration of the multi-probe meters, as well as careful notes about anything that could affect the sensor readings (e.g., any signs that a sensor was moved or was disturbed; replacement of sensors; adjustments to sensor depths). Any of these things could affect long-term trends, meaning they could cause a change that could mistakenly be interpreted as a trend when the change is really just stemming from a physical change in the sensor's position.

Table 7. Example of a sensor accuracy check that was performed on lake RMN data from Maine. The discrete vertical profile measurements (on the left) were compared to the closest sensor measurements (on the right) to see whether the difference fell within the accuracy specifications of the HOBO pro v2 sensor (within ±0.2°C). The cells highlighted in yellow were > ±0.2°C.

Discrete profile measurements				Closest sensor measurement				
DATE	TIME	Depth m	Temp °C	SiteID	Date.Time	Water.Temp.C	Water.LoggerID	Dif'ce
2018-09-18	11:57:59	0.18	21.66					
2018-09-18	11:58:46	0.84	21.46	Ellis~1.0m	2018-09-18 12:01	21.60	20312702	0.14
2018-09-18	11:59:54	1.86	20.38					
2018-09-18	12:01:09	2.89	19.08	Ellis~3.0m	2018-09-18 12:01	19.32	20172019	0.24
2018-09-18	12:02:57	3.89	18.39					
2018-09-18	12:06:39	4.91	16.66	Ellis~5.0m	2018-09-18 12:01	17.34	20172022	0.68
2018-09-18	12:09:43	5.91	11.85					
2018-09-18	12:10:37	6.86	9.65	Ellis~7.0m	2018-09-18 12:01	10.05	20172025	0.40
2018-09-18	12:11:57	7.87	8.6					
2018-09-18	12:13:12	8.9	7.82	Ellis~9.0m	2018-09-18 12:01	7.95	20172020	0.13
2018-09-18	12:14:28	9.89	7.75					
2018-09-18	12:16:01	10.52	7.72	Ellis~10.5m	2018-09-18 12:01	7.75	20172026	0.03

3.4 Equipment

Costs of the sensor arrays vary widely depending on the many factors described in the previous sections. Table 8 provides cost estimates for the main components of two arrays: one with five temperature sensors and one with five temperature sensors plus two DO sensors. It does not include accessories or retrieval equipment (e.g., grapple hook, side scan sonar, underwater camera). The array design worksheet in Attachment D also provides information on costs.

The biggest expense is the sensors. Most RMN partners are using temperature sensors that cost approximately $145 each and DO sensors that cost $1000-$1350 each. So far RMN participants have been able to obtain equipment for the arrays through loan programs with EPA regional offices, grants, gifts or through their monitoring programs.

When selecting sensors, considerations should include:

- Price
- Battery
    - How long do they last? Can you replace them?
- Rugged
    - Ideally should be able to withstand being frozen into the ice
- Accuracy (≤ 0.5°C)

- Compatibility
    - To save costs, minimize the number of unique data offload devices, software etc. you need

Figure 23 provides the specs on the two types of temperature sensors that most lake RMN partners are currently using (the Onset HOBO ProV2 and Pendant), while Figure 24 provides information on the two most commonly-used DO sensors at RMN lakes (the Onset HOBO DO sensor and PME miniDOT).

In addition to the sensors themselves, the Onset HOBO temperature and DO sensors require -

- Onset HOBO devices (Figure 25)
    - base station (needed to configure and launch the sensors) - $140
    - (optional but desirable) waterproof shuttle for downloading data - $280
- HOBOWare software
    - Free (temperature only)
    - Pro (needed for DO) – either $75 online (download only) or $99 (CD)

Table 8. Estimated costs for assembling two types of sensor arrays (one with temperature sensors only, and one with temperature sensors plus two DO sensors) for a 10-m deep lake, using the two-buoy design (Figure 4). Mention of trade names or commercial products does not constitute an endorsement or recommendation for their use; rather it is for descriptive purposes only.

Equipment	Description	Unit cost	Total cost	Potential cost reduction options
Temperature sensors	Five Onset HOBO pro v2 sensors positioned at the following depths: 1, 3, 5, 7 and 9.5 meters	$140	$700	Buy in bulk (this will reduce the unit cost); Use fewer sensors (2 minimum); Use cheaper sensor (e.g., $59 HOBO Pendant)
DO sensors	Two DO sensors positioned at the following depths: 1 and 9.5 meters	PME miniDOT $1100; HOBO DO $1350	$2700	Use the cheaper sensor (PME miniDOT); Deploy one instead of two DO sensors; Do not deploy any DO sensors.
Rope	30-meters of 3/8" floating pot warp for the instrument line, grab line, recovery loop and rope between the surface and subsurface buoys	Prices vary. Hamilton Marine in Maine sells a 36-lb coil (about 365-m or 1200-ft) for about $75 (which is about 20 cents/meter)	$6*	Buying in bulk (in this case, a 36-lb coil) has a relatively high up-front cost but the price per unit is cheaper and there may be opportunities to split a bulk purchase with other regional partners (in this example, 365 meters is enough rope to outfit about twelve 10-m deep lakes)
Floats	2 primary buoys - closed cell, 6X14”	$6	$12	Use one instead of two buoys; Use cheaper floats (like the pool noodles in Figure 11)
	3 secondary floats (gill-net type)	$1.50	$5	Do not use secondary floats
Anchors	15-lb mushroom anchor, vinyl coated for instrument line	$39	$39	Us cheaper options such as concrete blocks ($1.50/piece), homemade concrete anchors or nylon mesh bags filled with rocks
	5-lb standard Danforth anchor (300-lb holding power) for grab line	$25	$25	
Zip ties	Package of 100 heavy-duty 8” zip ties	$6	$6	Do not skimp on the zip ties!
Total: 5 temperature sensors + zero DO sensors			***$788***	
Total: 5 temperature sensors + two DO sensors			***$3288***	

*30 meters of rope at 20 cents/meter = $6

Commonly-used water temperature sensors on low budget arrays

	Pendant	Water Temp Pro v2
Temperature Range (in water)	-20 to 50C	-40 to 50C
Accuracy (0 to 50°C)	0.54°C	0.2°C
Depth Rating	30m	120m
Battery	User-replaceable	Factory-replaceable
Typical use battery life*	1 year	6 years
Special Features	Also includes either a relative light sensor or alarm indication	Protective boot available
Price	$47 (6.5K of readings) $59 (52K of readings)	$129 (64K memory)

*1 minute or greater logging interval

Battery life is affected by temperature & logging interval (extremely cold or hot temperatures and logging intervals faster than one minute may significantly reduce battery life)

proV2

Not an endorsement!

Pendant	Water Temp Pro v2
	
$47 to $59	$129

Pendants are cheaper and have relative light sensors, but require more maintenance -

- Replace batteries 1X/year – (CR2032 batteries)
- More limited data capacity than the pro v2; if you can only make one site visit per year, we recommend the 52K version, which has enough memory to record at 60-minute intervals for a year
- Light sensors are prone to fouling, even in high quality lakes

Both sensors have good survival rates if they get frozen into the ice.

Figure 23. The Onset HOBO ProV2 and Pendant temperature sensors are currently the most commonly-used temperature sensors at RMN lakes. This does not constitute an endorsement or recommendation for their use; rather it is for descriptive purposes only. Costs have increased. Pendants are now ~$75 and pro V2s are $145.

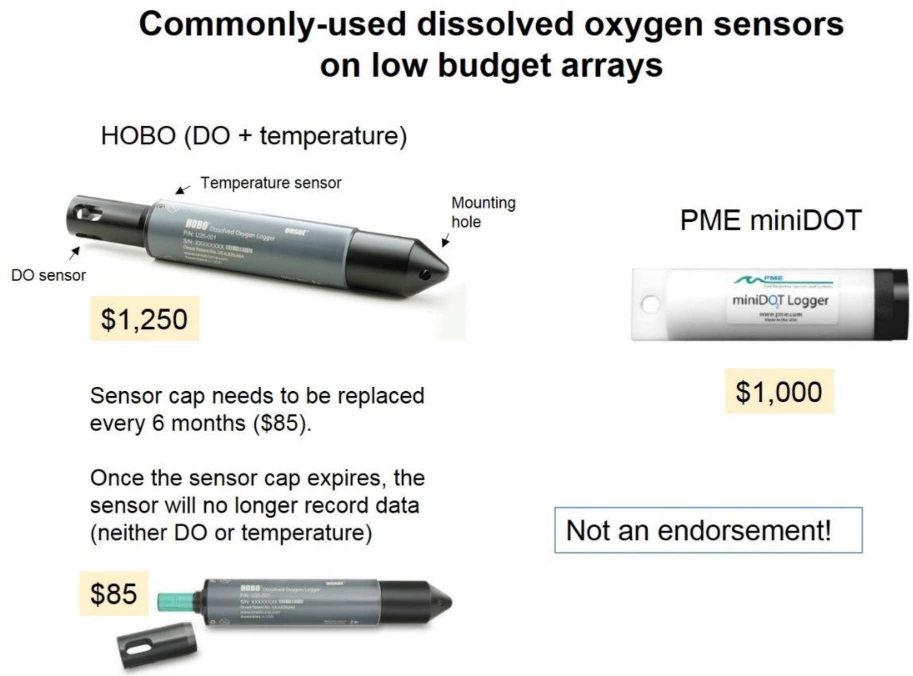


Figure 24. The Onset HOBO DO and PME miniDOT sensors are currently the most commonly-used DO sensors at RMN lakes. This does not constitute an endorsement or recommendation for their use; rather it is for descriptive purposes only. Costs have increased. Onset DO sensors are now $1350 and sensor caps are $125.

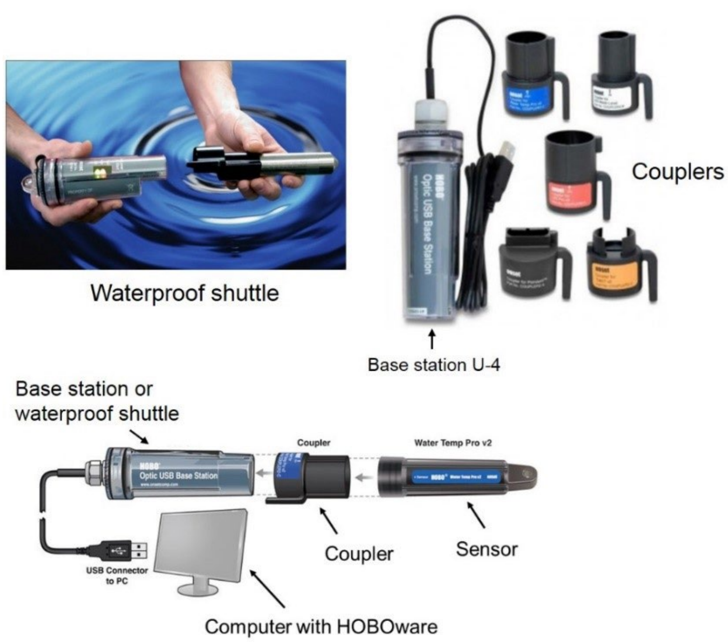


Figure 25. The Onset HOBO sensors require a base station and HOBOware software to configure and launch the sensors and to download data. A waterproof shuttle is available for data downloads as well. The couplers (which come with the base station) make the base station compatible with the various HOBO sensors, meaning the same base station can be used for the Pendant, ProV2, DO and U20 series sensors.

3.5 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 the continuous sensor arrays 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[6]:

- U.S. EPA (2014) - Appendix C. Forms for temperature sensor accuracy checks
- U.S. EPA (2014) - Appendix D. Temperature sensor deployment and tracking forms
- U.S. EPA (2014) - Appendix G. Mid-deployment/maintenance check form.
- U.S. EPA (2014) -Appendix H. Tips on record keeping and QA/QC during the data processing step.

3.6 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, it can calculate basic statistics (daily/monthy/seasonal/annual time periods) and generate time series plots. For more information, contact Jen.Stamp@tetratech.com

Another free, open-source tool called LakeMonitoR has been developed for visualizing and summarizing the vertical profile sensor data. It is also available as either a website/Shiny app (https://nalms.shinyapps.io/LakeMonitoR/) or R package (https://leppott.github.io/LakeMonitoR/). For some outputs, it utilizes code from the existing rLakeAnalyzer R package (Winslow 2019, Read et al. 2011; https://cran.r-project.org/web/packages/rLakeAnalyzer/rLakeAnalyzer.pdf).

The workflow we envision is: 1) QC your data from each individual depth (e.g., using ContDataQC); 2) use the 'combine data' function in LakeMonitoR to combine your QC'd files from each depth to get one file with data from all depths; 3) load the combined data file; and 4) generate plots and summary statistics. LakeMonitoR outputs currently include:

- Stratification events
    - Start and end dates, duration (# days), based on two approaches
        - Temperature change per 1-meter interval, with onset when there is > 1°C temperature change per 1-meter interval, anywhere in the water column

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

    - Difference between surface and bottom temperature, with onset when values are > 1°C and the end point when values are < 1°C
- Basic statistics that characterize temperature in the epilimnion and hypolimnion (minimum, maximum, mean, median, percentiles)
- Temperature difference between epilimnion and hypolimnion (a measure of stratification strength)
- Thickness/extent of the metalimnion
- Thermocline depth
- Center of buoyancy (an alternate measure of thermocline depth)
- Buoyancy frequency
- Schmidt stability index
- Date of minimum dissolved oxygen (DO) concentration
- Number of days DO concentrations are below a user-defined level (e.g., 2 mg/L is often used to define hypoxic conditions)
- The 'temperature at 3 mg/L DO' (TDO3) metric

Graphical outputs:

- Stratification events (duration and timing)
- Multi-depth time series plot for temperature
- Thermal heat map
- DO time series plot that includes a user-defined threshold line
- Time series plots for wind or other variables
- Oxythermal map that shows areas with suitable thermal and dissolved oxygen habitat, based on user-defined thresholds

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Appendix A

Field form for discrete profile measurements (EPA NLA 2017)

FORM IP-1: NLA 2017 INDEX PROFILE (Front)

Reviewed by (initial): ______

Site ID: NLA17_ ______ Date: __ / __ / 2 0 1 7 Time of Arrival at Index Site (hh:mm) __ : __

Coordinates		Latitude	Longitude	
INDEX SITE	Decimal Degrees NAD 83	__ . ______	– __ . ______	Type of GPS Fix: O 2D O 3D

Precipitation: O NONE O LIGHT O HEAVY Surface Conditions: O FLAT O RIPPLES O CHOPPY O WHITECAPS

Odor: O YES O NO Description:

Scum: O YES O NO Description:

Index Site Depth (m): XX.X __ . _ Comments:

Method Used: O LINE O SONAR O POLE O ESTIMATE

CALIBRATION INFORMATION

Instrument manufacturer and model:

Instrument ID number: Operator:

TEMPERATURE	Thermometer Reading (°C) XX.X	Sensor Reading (°C) XX.X	Comments
	__ . _	__ . _	

DO	Elevation	OR	Barometric Pressure (mm Hg)	Calibration Value	Displayed Value	Flag
	______ (m)		______	__ . __ O mg/L O %	__ . __ O mg/L O %	

pH

Cal. STD 1 Description	Cal. STD 1 Value	Cal. STD 2 Description	Cal. STD 2 Value
	__ . __		__ . __

Calibration Verified with Quality Control Sample (QCS)

QCS Description	QCS True	QCS Measured	Flag
	__ . __	__ . __	

CONDUCTIVITY

Cal. STD 1 Description	Cal. STD 1 Value	Cal. STD 2 Description	Cal. STD 2 Value

Calibration Verified with Quality Control Sample (QCS)

QCS Description	QCS True (μS/cm @25°C)	QCS Measured (μS/cm @25°C)	Flag

Flag	Comments

FORM IP-1: NLA 2017 INDEX PROFILE (Back)

Reviewed by (initial): ______

Site ID: NLA17_ ______________ Date: ___ / ___ / 2 0 1 7

Submitted data via eFile ○ **DISSOLVED OXYGEN, TEMPERATURE, AND pH PROFILE**

Intervals (m): Surface to 20 m = every 1 m; 20-50 m = every 2 m; last reading 0.5 m above bottom[a]

[a] If the site depth is <3 m, take readings at the surface, every 0.5 m, and 0.5 m above bottom.

[b] METALIMNION = The region of the profile where the temperature changes at the rate of 1 °C or greater per meter of depth. Indicate the depth of the top of the metalimnion with a 'T', and the bottom of the metalimnion (when the rate change becomes less than 1 °C per meter) with a 'B'. After the metalimnion is encountered, take readings every 1 m until bottom of the metalimnion is reached.

Depth XX.X	O_2 (mg/L) XX.X	Temp. (°C) XX.X	pH X.XX	Cond. (µS/cm@ 25°C) XX	Meta-limnion [b] (T, B)	Flag	Depth XX.X	O_2 (mg/L) XX.X	Temp. (°C) XX.X	pH X.XX	Cond. (µS/cm@ 25°C) XX	Meta-limnion [b] (T, B)	Flag
Surface													
							Dup Surface						

Is the Duplicate O_2 reading within ±0.5 mg/L of the initial surface reading? ○ YES ○ NO

If no, calibration verified? ○ YES ○ NO

Flag	Comments