

Standard Operating Procedure #14: Moored Temperature Arrays

Version 1.0 (2021)

In Water Quality Monitoring Protocol for Inland Lakes: Great Lakes Inventory and Monitoring Network

Prepared by

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Revision History Log

The following table lists all edits and amendments to this document since the original publication date. Information entered in the log must be complete and concise. Users of this standard operating procedure will promptly notify the project manager and/or the Great Lakes Network (GLKN) data manager about recommended and required changes. The project manager must review and incorporate all changes, complete the revision history log, and change the date and version number on the title page and in the header of the document file. For complete instructions, please refer to Revising the Protocol, SOP #13.

Previous Version #	Revision Date	Author (with title and affiliation)	Location in Document and Concise Description of Revision	Reason for Change	New Version #
Add rows as needed for each change or set of changes tied to an updated version number					

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14.0 Introduction

Long-term water quality monitoring by the Great Lakes Inventory and Monitoring Network (GLKN) takes place at inland lakes and large rivers across nine parks in the western Great Lakes region. Complete descriptions of water resources monitored and monitoring methodology are detailed in GLKN's water quality monitoring protocols for inland lakes (Elias et al. 2015) and large rivers (Magdalene et al. 2016). This standard operating procedure (SOP), which resides under the umbrella of GLKN's Inland Lakes Monitoring Protocol but is also relevant to the Large Rivers Monitoring protocol, focuses on continuous monitoring of lake water temperature.

Lake water temperature is an important driver of ecological processes of lakes. All aquatic biota have an optimal temperature range that allows maximum growth and health. Water temperature also has an important influence on lake physical processes. Differences in temperature drive differences in density of water, which allows deeper lakes to stratify into separate layers, often with disparate chemical and physical characteristics.

As a core water quality parameter (see Section 1.2.1 of protocol narrative and SOP #6) water temperature is collected at all monitoring sites. We measure temperature with a multiparameter sonde at one-meter intervals, from the surface of the lake to the bottom, three times during monthly sampling during the ice-free time of the year, typically June-August in most GLKN parks (Damstra et al. 2014, Elias and Damstra 2012, Elias and Damstra 2011, Elias and VanderMeulen 2008). This discrete monitoring is one way to observe and measure thermal stratification in lakes.

Thermal stratification can also be measured through instrumentation that allows for continuous water temperature monitoring. This can be accomplished through use of profiling buoy systems, thermistor strings, and moored temperature arrays (arrays), which are further described below.

Understanding the timing of formation, persistence, and strength of thermal stratification are of special interest to the GLKN and are the focus of this standard operating procedure (SOP). In the sections that follow we describe in detail construction, deployment, and recovery of temperature monitoring equipment. Setting up the equipment to collect data; downloading, managing and performing QA/QC checks on the data is also explained, as well as some basic data analysis techniques.

This data will be used to assess the timing of ice on and ice off, and formation, strength, and persistence of summer thermal stratification, in the context of expected future increases in air temperature (i.e., climate change). In concert with discrete data collected under our protocols for Inland Lakes (Elias et al. 2015) and Large Rivers (Magdalene et al. 2016), this data can be used to draw inferences about availability of aquatic habitats available to different biota, including species of cold water fish such as trout. For example, there are examples of changes in habitats available to fish in summer based on changes in temperature, especially when taken together with dissolved oxygen (Guzzo and Blanchfield 2017, Hansen et al. 2016, Jacobsen et al. 2010, Jacobsen et al. 2008). Additionally, changes in the timing of ice on/off can have impacts on other biota, including causing phytoplankton blooms (Pierson et al. 2011, Elias and VanderMeulen 2008, Elias and Damstra 2011).

14.1 Continuous Profiling Equipment

There are many types of equipment used to obtain continuous profiles in lakes, ranging from large, costly, semi-permanent systems that upload data to the internet in near-real time, to portable, relatively inexpensive systems that can be constructed by NPS staff and require field visits to download the data. Although not intended to be comprehensive, we detail the different types of systems that can be used and provide detailed information about the system that GLKN has chosen to utilize.

14.1.1 Profiling Buoy Systems

Many profilers are based on a floating platform, such as a large buoy, a pontoon craft, or a fixed station, such as on a dam or a pier (Figure 1). These systems can have a range of instruments attached, including sondes that can be lowered automatically through the water column to collect a profile of a range of physical and chemical characteristics in addition to temperature. These instruments often have a weather station installed above the surface of the water and also may collect other data such as flow. This type of equipment is very useful, but requires a high degree of technical knowledge to operate, and is very costly. Additionally, these systems are not well suited to remote areas because they can be large and difficult to transport in areas without motorized vehicles. Also, large highly-visible instrument platforms on the surface of lakes may not be compatible with federally-designated wilderness restrictions.

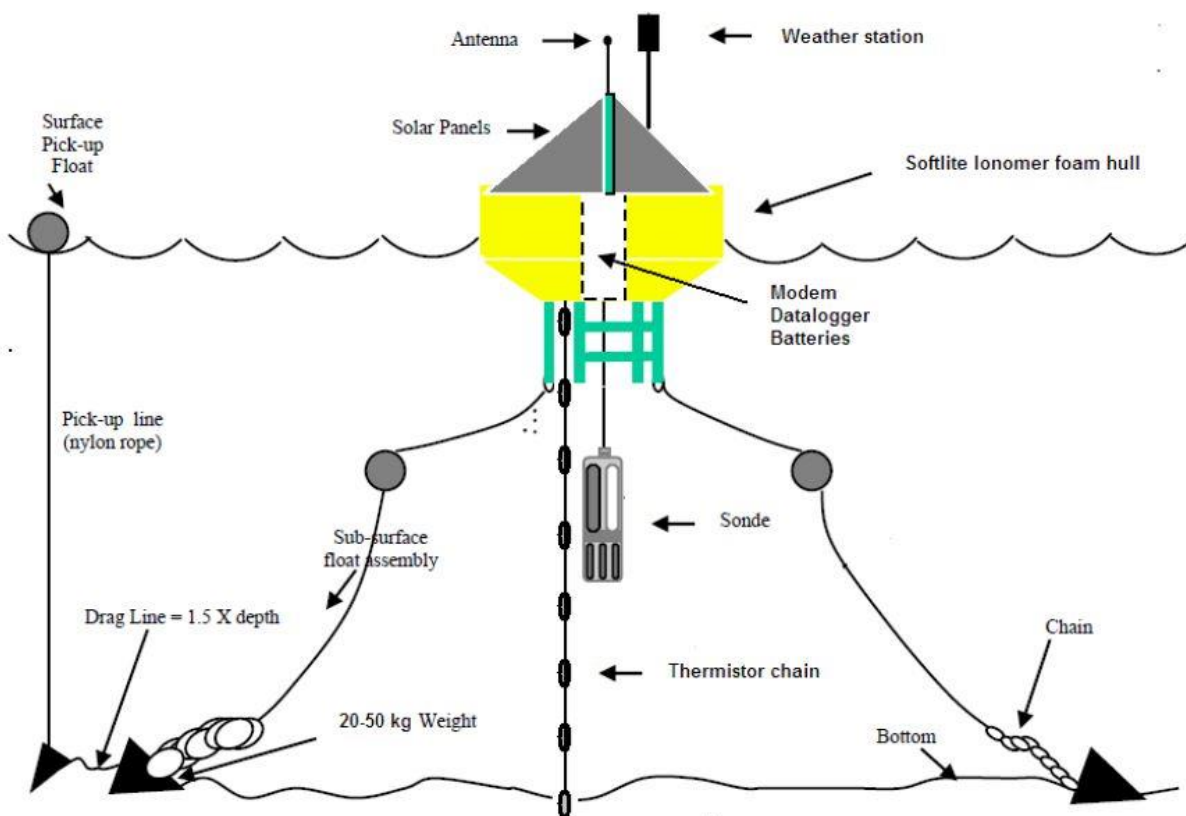


Figure 1. Example of an automated profiling buoy system where a thermistor chain is attached to the bottom of the buoy (from Laas et. al 2016).

14.1.2 Thermistor Chain

A second type of equipment that requires an external data logger is known as a thermistor string or a thermistor chain. These instruments are fabricated into a cable, with a data socket at the top and thermistors spaced a pre-determined distance apart (Figure 2). Like the automatic profilers, these also require an external data logger and a power source in a buoy or a platform above the water. They also allow all time series for each depth to be collected together. These systems can be attached to a profiler buoy data logger to capture additional temperature measurements but are costly; they are typically custom built and usually rely on the deployment of a floating platform similar to those shown in Figure 1 (Laas et. al 2016).



Figure 2. Thermistor chain to be deployed under an automated profiling buoy system (photo from University of Michigan Ocean Engineering Laboratory).

14.1.3 Moored Temperature Arrays (array)

A third type is similar to the thermistor chain in Figure 2 but is constructed of individual sensors spaced a known distance apart. Sensors are attached to a rope vertically suspended below a buoy and attached to the lake bottom using an anchor system (Figure 3). The Southwest Alaska Inventory and Monitoring Network (SWAN) of the NPS has deployed arrays on Lake Clark, Naknek Lake, and other very large, deep, glacial lakes (Shearer et al. 2015). This is the system that GLKN uses and that will be detailed in this document.



Figure 3. An array being deployed at Lake Richie, Isle Royale National Park. Sensors are clearly visible and are spaced 1 m apart (NPS-GLKN photo).

14.1.4 GLKN's Preferred Option

After examining the three previous options, we determined that arrays are our preferred option for continuous monitoring of water temperature because they are less expensive and less conspicuous than the other options. Our SOP has been modified from the SWAN protocol (Shearer et. al 2015) to reflect the smaller, shallower inland lakes found in GLKN parks. The SWAN arrays are deployed via a large boat with a winch and a davit. This would not be possible in most lakes in GLKN parks, as several of the lakes where arrays are to be used are in federally designated wilderness areas or in other backcountry areas inaccessible to motorboats. The arrays in GLKN lakes need to be able to be carried into the backcountry in backpacks and deployed and tended from canoes or small boats. They may also be deployed with or without a surface buoy, depending on the need to protect wilderness values, boat traffic, or to protect viewsheds as desired by park management in non-wilderness areas.

14.2 Sensor Types, QA/QC, and Programming

Disclaimer: Use of product names in this section is for purposes of specificity and is not an endorsement, explicit or implied, by the National Park Service.

14.2.1 Sensors

The arrays are typically outfitted with Onset Water Temp Pro V2 and/or Onset HOBO U-20 pressure/temp loggers. Both types of loggers are programmable using the Onset HOBOWare proprietary software, and can be set to record data on an interval set by the user. Both types of loggers record temperature using an internal thermistor. In addition to temperature, the U-20 records pressure. This can be converted to water depth using a reference barometric pressure (BP) from a second U-20 in the air on site or a third-party BP reference, such as a weather station. Loggers are programmed and data is read out from loggers using an optical shuttle in the field, and downloaded to a PC later, or using an optical base station attached to a PC in the office.

Other instruments, such as HOBO pendant-type light/temp or instruments from other manufacturers or with other instruments may also be used. However, light loggers and other instruments may have problems with biofouling, have shorter battery life, and may need to be serviced more often (Shearer et al. 2015, GLKN unpublished data). Loggers that collect other parameters such as the HOBO U-26 temperature/dissolved oxygen logger, PME miniDOT dissolved oxygen/temperature logger, or multiparameter sondes have not yet been deployed on arrays in GLKN parks at this time. If this type of probe is to be deployed, follow calibration guidelines in the GLKN Inland Lakes and Large Rivers protocols (Elias et al. 2015, Magdalene et al. 2016) and best practices recommended by the equipment manufacturer.

14.2.2 QA/QC

Follow quality assurance/quality control procedures in SOP #12. Measurements are to be collected in a manner to minimize artifacts that can bias the result. This section will primarily refer to quality assurance/control of loggers similar to HOBO Water Temp Pro V2. If other sensors or multiparameter sondes are deployed then QA/QC techniques specific to the equipment will be adopted (Wagner et al. 2006, Elias et al. 2015, Magdalene et al. 2016).

Prior to initial deployment all sensors must undergo QA/QC procedures to ensure that they are collecting defensible data. At minimum, the sensors should be checked against a NIST-reference thermometer, in an ice-water bath ($\approx 0^{\circ}\text{C}$) and at room temperature ($\approx 20^{\circ}\text{C}$) to make sure that the loggers are within $\pm 0.2^{\circ}\text{C}$ of the NIST thermometer (Wagner et al. 2006, Elias et al. 2015, Magdalene et al. 2016).

To perform these checks, loggers should be launched and programmed to collect data at 1-minute intervals (see below section on logger programming). The loggers are submerged in the water bath with the NIST thermometer and allowed to equilibrate for at least 15 minutes. Five minutes before the QA/QC test is to start, the water bath should be stirred thoroughly and continuously. Stirring will continue throughout the QA/QC test to ensure a uniform temperature throughout the bath.

At a pre-determined time when the loggers should be logging, record the temperature of the NIST thermometer once every minute. Continue this for at least eight minutes, so that AMS+ (Elias et al. 2015) can be calculated. Download data from the loggers, and save to an appropriate location so it will be preserved. If any sensors do not meet the criteria described above (± 0.2 °C of NIST thermometer), they should be retested, and if they do not meet the criteria a second time, they should be returned for service, and replaced with sensors that meet QA/QC criteria.

Pressure sensors (depth) should be checked against one another, and compared to an accurate pocket altimeter or multiparameter sonde that measures pressure to make certain that the sensors are reasonably accurate. The pressure sensors should be within 1.0 kPa of each other and also ± 1.0 kPa of the reference pressure. The pressure value of 1.0 kPa corresponds to approximately 0.1 m of water depth (<https://www.sensorsone.com/kpa-to-mh2o-kilopascals-to-metres-of/>, accessed 19 June 2017), which is the reporting resolution, estimated bias, and stabilization criteria for depths obtained with pressure sensors on multiprobes in the GLKN Lakes Protocol Narrative (Elias et al. 2015). Nearby weather stations can be used to assess accuracy of loggers, but since pressure will vary over altitude and between locations, caution should be taken when using weather stations for this purpose.

14.2.3 Programming

This section will focus on programming for Onset HOBO Water TempPro V2 and U-20 Temp/and Depth loggers (pressure is logged by U-20 loggers simultaneously with temperature). If other types of loggers are deployed, use this section as a guideline for file names, file types, date/time formats, measurement units, and logging intervals. The manufacturer's instructions for the equipment in use should be followed, as well as guidelines published by other agencies that use this equipment such as the U.S. Geological Survey (Wagner et al. 2006).

Following the manufacturer's instructions for connecting the Hobo waterproof shuttle or Optic Base Station to your computer using a USB cable. Attach the logger to the shuttle/base station using the appropriate coupler. Follow the instructions for your shuttle/base station to establish communication with the logger before attempting to launch.

Prior to launching the loggers for the first time, HOBOWare must be set up to output data in the proper units, date/time formats, and data layouts. Failure to do this can lead to inconsistencies that can make later data management difficult. To begin this process, open HOBOWare and click "File" and "Preferences". Under the "General" tab, make your setting match those pictured in Figure 4. Set the export file type to "Text (.txt or .csv)" and the Export table data column separator to "Comma (,)". Check the boxes "Include logger serial number" and "Include sensor serial number or label if available". Make the date format "M D Y", the date separator "Slash (/)", the time format "24-Hour", the positive number format "1,234.56" and the negative number format "-123".

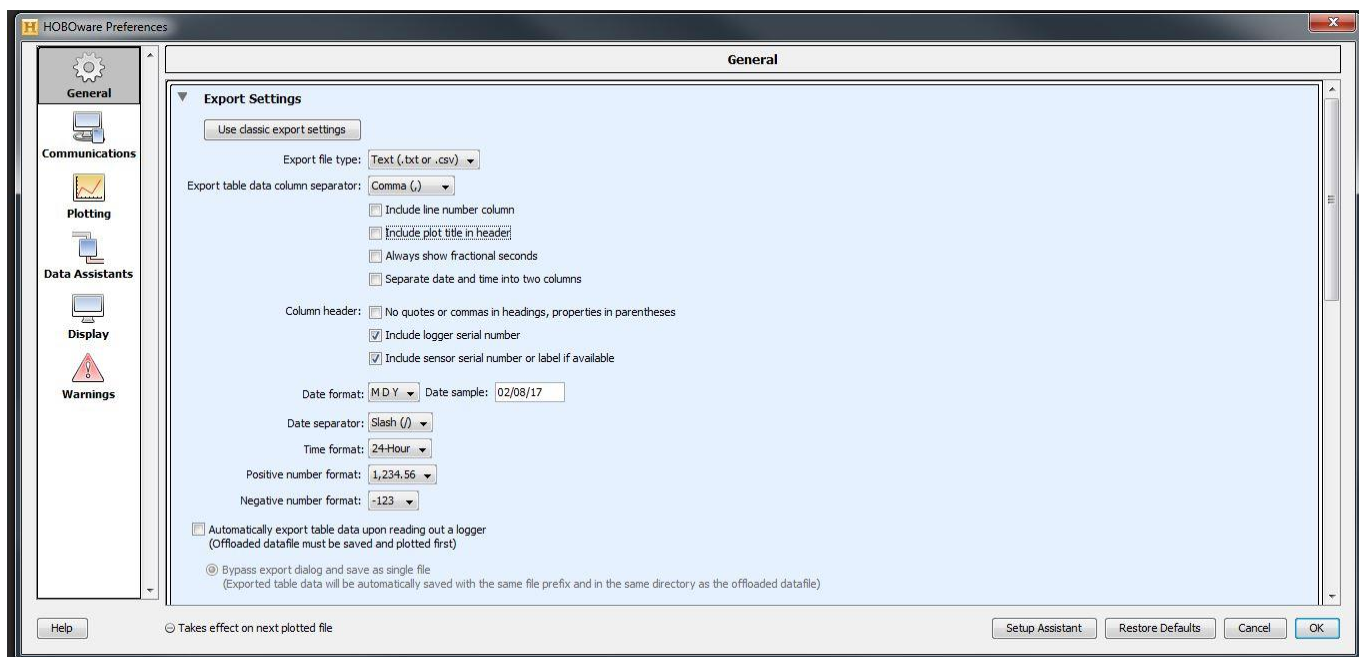


Figure 4. General settings to be applied to HOBOWare Preferences.

Next, click on the “Display” tab (Figure 5). You will need to change the unit system from the default US (“English”) to SI (metric). Set Date format to “M D Y”, date separator to “Slash (/)”, year format to “4-digit year”, time format to “24-Hour”. Under “Series”, select “Logger’s default” as sort order, and check the box to “Display logger’s battery series in the last position”.

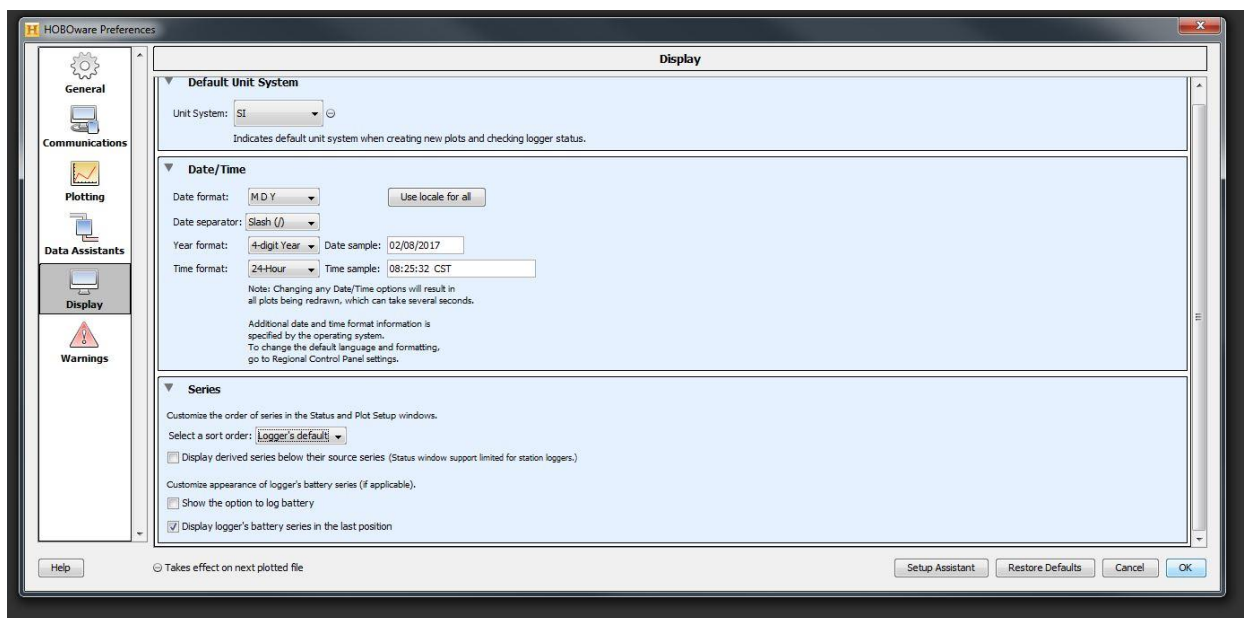


Figure 5. Display settings to be applied to HOBOWare Preferences.

File names will have the following format: “Data Owner (4 letter org code) Location (Site_ID) _Nominal Depth (m) _Instrument Type, Instrument Serial Number. For example, a temperature logger with the s/n 9816129 owned by the GLKN that is deployed at 15m on Grand Sable Lake (Site_ID = PIRO_01) at PIRO is named “GLKN_PIRO_01_15.0m_Temp_9816129” (Figure 6).

Similarly, a temperature and depth (pressure) probe with the serial number 9916128 deployed at the same lake and park at 3m would be named “GLKN_PIRO_01_3.0m_TempPres_9916128”. This convention allows instruments deployed at the same depth to be discerned from one another. If instruments are used that measure parameters other than temperature and depth, the project manager and data manager should be consulted to determine the file name convention for those parameters.

Launch Logger

HOBO U22-001 Water Temp

Name:

Serial Number: 9816129

Deployment Number: 10

Battery State: GOOD

Sensors

Configure Sensors to Log:

☒ 1) Temperature

Deployment

Logging Interval	Samples	Logs until
1) 1 hour	43474	5.0 years

Start Logging:

☐ Skip launch window next time

Figure 6. Launch settings for a HOBO Water Temp Pro V2 temperature logger.

Instruments will be programmed to collect data at 60-minute intervals, which will be sufficient to discern temperature-driven phenomena in lakes, and will prevent the logger memory from filling up during a typical deployment period of 9–12 months, or longer. This may be adjusted depending on program goals and instrument types. Typically, loggers will be set for a delayed start, with the start time prior to beginning array deployment on the day of the array deployment (Figure 6).

14.3 Array Construction and Maintenance

Similar to the array system described in Pierson et al. (2016), GLKN arrays are comprised of vertical line with loggers attached, supported in the water column by a buoy, anchored to the bottom, with a horizontal line stretching along the bottom to allow the array to be hooked with a grappling hook. The buoy is suspended below the surface of the water and the array is meant to be deployed year-round, including under ice.

The GLKN method of array construction (Figure 7) is a single line configuration similar to Pierson et al. (2011) and Pierson et al. (2016) (Figure 8). Alternatively, arrays for very deep lakes (>30 m) may be constructed using the two-line design developed by SWAN (Figure 9; Shearer et al. 2015).

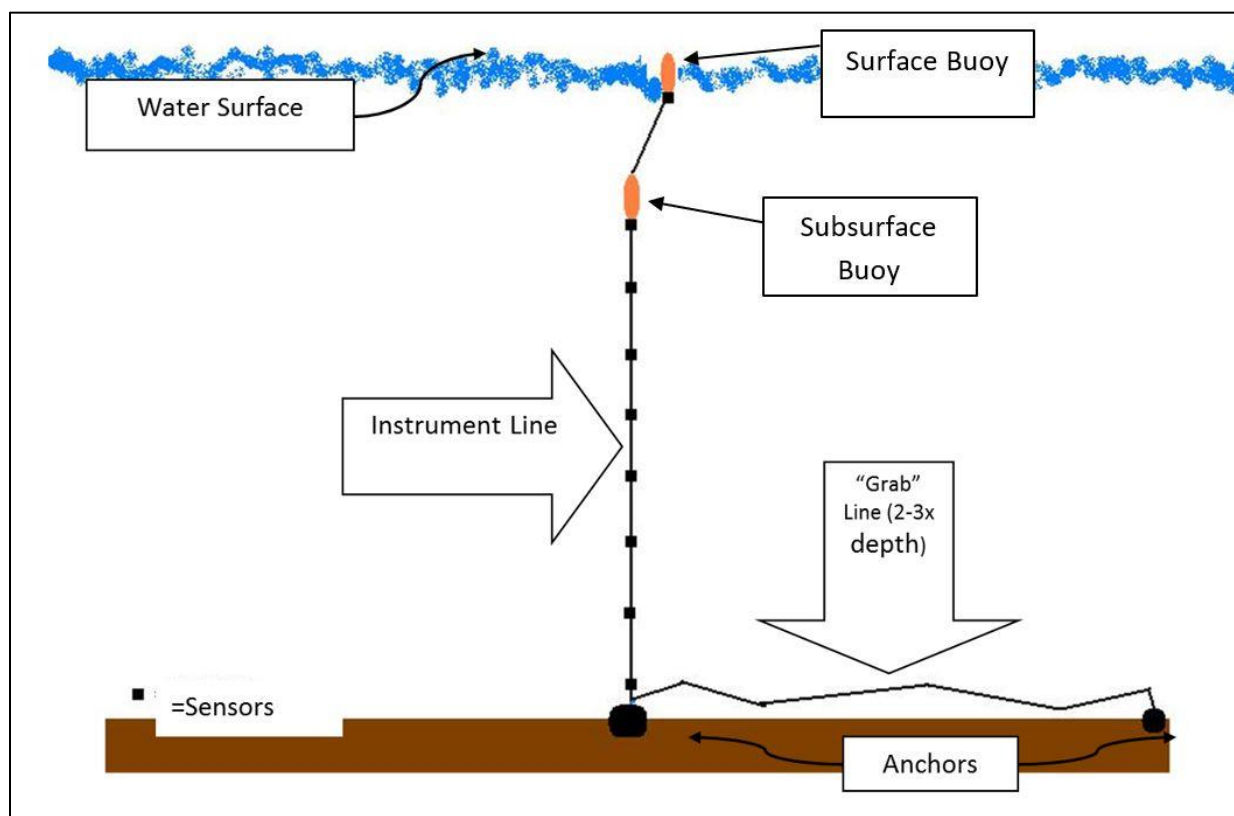


Figure 7. Design of a typical array constructed by GLKN. This design assumes floating lines to ensure that the grab line stays above the bottom to allow easier retrieval with a grappling hook. If using non-floating lines, use the design in Figure 8.

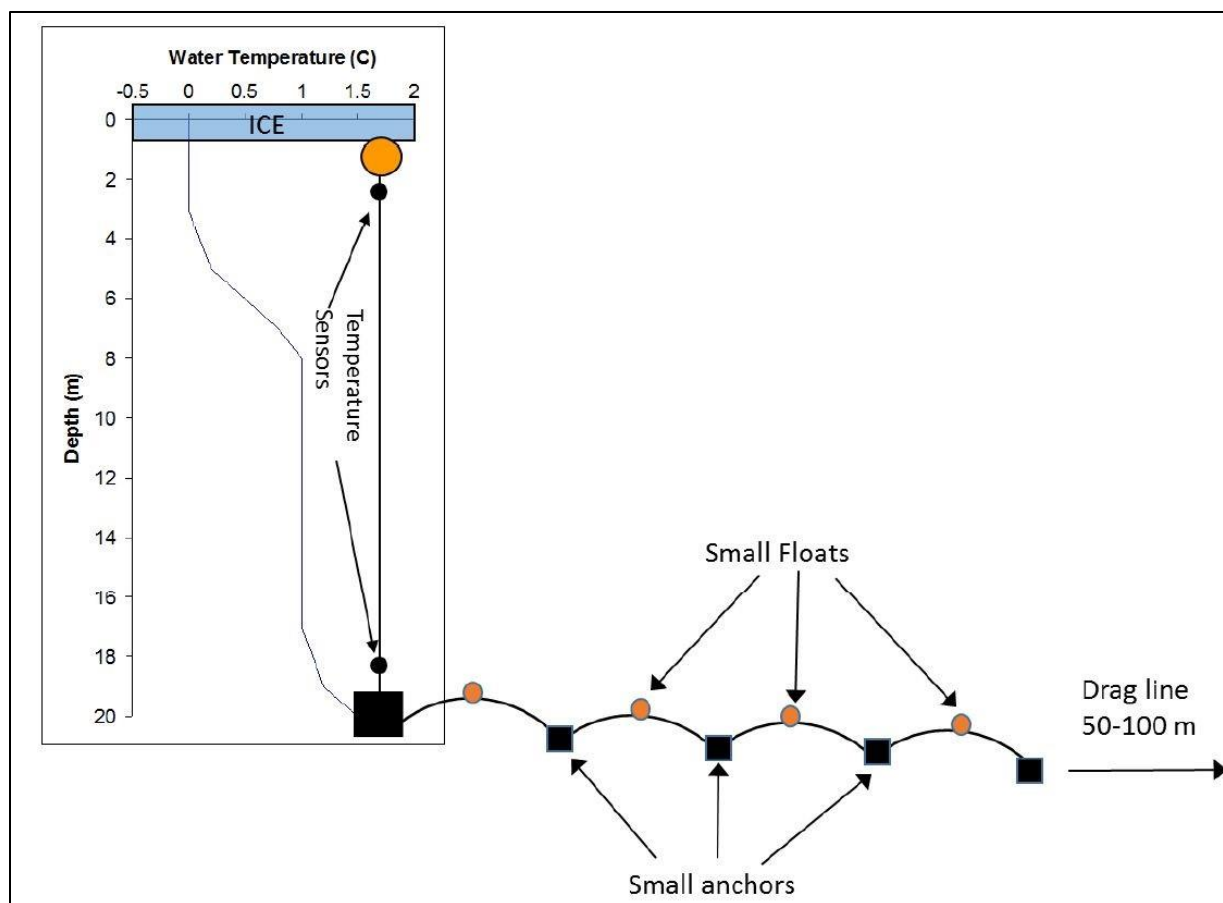


Figure 8. An alternate design for a moored array, with floats and additional small anchors on the grab (drag) line. Using small floats (similar to floats used on gill nets or fyke net leads) will be necessary if using a non-floating line, like certain nylon lines. From Pierson et al. (2016).

The single line array consists of an instrument line leading from a sub-surface buoy situated below the maximum extent of the ice and deep enough to be below the maximum depth of most boat motors (usually 1–2 m) below the surface of the water down to an anchor on the bottom of the lake. At the bottom of the instrument line also attached to the anchor is a floating grab (drag) line, 50–100 m, with final length from 2- to 3-times longer than the instrument line. The grab line is attached to one or more small anchors depending on line material and length. Field crews use a grappling hook to snag the grab line and allow for array retrieval when surface buoys are not used (e.g., when they are removed in the winter), not visible from the surface, or are lost. If the array is deployed close to shore, the grab line may be replaced with a sinking line and tied to an object on shore and followed out to the array (Pierson et al. 2016).

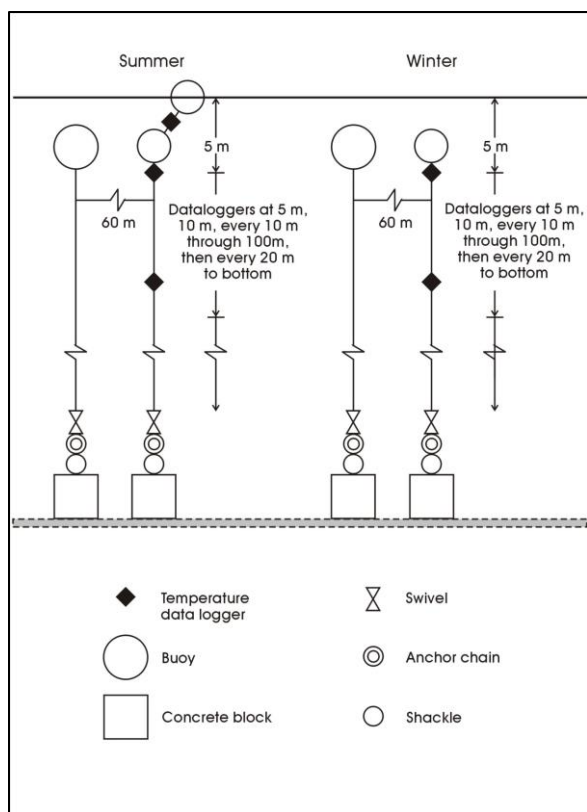


Figure 9. Two-line array configuration, as used at SWAN. From Shearer et al. (2015).

During the ice-free seasons, a short buoy line with a surface sensor may be attached to the main sensor line to allow staff to easily find, retrieve, and maintain the array. In wilderness areas, or areas where park management does not want a visible buoy on the surface of the water, the array may be deployed without a surface buoy.

14.3.1 Logger Placement

The type and total number of loggers to be used depends on the depth of the lake and the design of the array. Before launching the loggers, record all the serial numbers of the loggers and assign them to the nominal depth they will be deployed at. Label the case of the loggers with the Site ID, nominal depth, and month and year launched as is shown in Figure 10. Track these with the serial numbers in a spreadsheet as shown in Figure 11 that is used to comprise the logger metadata.

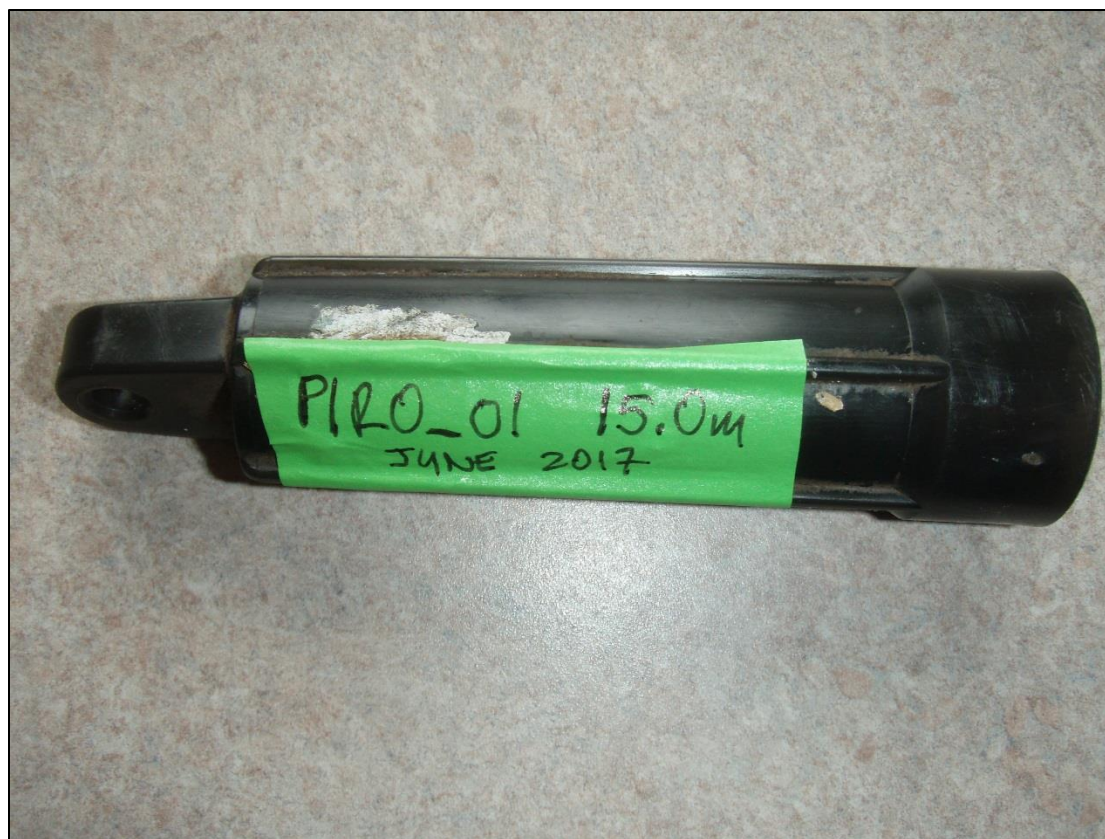


Figure 10. A HOBO Water Temp Pro V2 labeled prior to deployment. In this example, waterproof lab labeling tape and a permanent marker was used, but paint pen may be used as well.

Description	Ownership	Location	Property #	Serial #	Comments	Recommendations	Current Software/Firmware Version	Additional Notes	Nominal depth at deployment (m)	Hoboware Filename
Hobo water level logger (30 ft depth) U-20	GLKN	SLBE	329	9800746	Deploy to SLBE_05 Spring 2016				8.0m nominal depth	GLKN_SLBE_05_8.0m_TempPres_9800746
Water Temp Pro V2 (U22-001)	GLKN	SLBE	NA	10792902	Deploy to SLBE_05 Spring 2016		1.06		0	GLKN_SLBE_05_0.0_Temp_10792902
Water Temp Pro V2 (U22-001)	GLKN	SLBE	NA	10792903	Deploy to SLBE_05 Spring 2016		1.06		1.5	GLKN_SLBE_05_1.5m_Temp_10792903
Water Temp Pro V2 (U22-001)	GLKN	SLBE	NA	10792904	Deploy to SLBE_05 Spring 2016		1.06		2	GLKN_SLBE_05_2.0m_Temp_10792904
Water Temp Pro V2 (U22-001)	GLKN	SLBE	NA	10792905	Deploy to SLBE_05 Spring 2016		1.06		3	GLKN_SLBE_05_3.0m_Temp_10792905
Water Temp Pro V2 (U22-001)	GLKN	SLBE	NA	10792906	Deploy to SLBE_05 Spring 2016		1.06		4	GLKN_SLBE_05_4.0m_Temp_10792906
Water Temp Pro V2 (U22-001)	GLKN	SLBE	NA	10792907	Deploy to SLBE_05 Spring 2016		1.06		5	GLKN_SLBE_05_5.0m_Temp_10792907
Water Temp Pro V2 (U22-001)	GLKN	SLBE	NA	10792909	Deploy to SLBE_05 Spring 2016		1.06		6	GLKN_SLBE_05_6.0m_Temp_10792909
Water Temp Pro V2 (U22-001)	GLKN	SLBE	NA	10792910	Deploy to SLBE_05 Spring 2016		1.06		7	GLKN_SLBE_05_7.0m_Temp_10792910

Figure 11. Example showing spreadsheet tracking logger information deployed on an array in Bass Lake (SLBE_05) at Sleeping Bear Dunes National Lakeshore.

In deciding where loggers should be placed on the line, consideration must be made of the depth of the lake and types of instruments in use. For GLKN loggers are typically placed at 1-meter intervals. In some deeper (>20 m) lakes, such as Little Trout Lake at Voyageurs National Park, temperatures do not vary much below 15 meters, and loggers are placed at 5-meter intervals below 15 meters. This determination should be made based on temperature profiles collected during discrete visits. Alternatively, if the only goal of an array is to track ice on and ice off, only two loggers need be used; one about 0.5 m above the bottom and one just below the surface (1–2 m), situated to remain just below the ice in the winter. Also, consider using solar radiation shields on loggers that are

shallower than 2–3 meters, as solar radiation has been shown to bias water temperature readings at those depths (GLKN, unpublished data). Depth (pressure) loggers should be placed as close to the bottom of the array as the specifications for the instrument will allow. This will allow estimation of water depth over the instrument. For more on the estimation of water depth, see section 14.4.3.1, Creation of Estimated Derived Instrument Depth Time Series, below.

14.3.2 Materials

Arrays are to be constructed from synthetic line of large enough diameter to be strong and be easy for members of the field crew to grip (GLKN uses ½-inch-diameter floating hollow core braided polypropylene line). The line will be selected based on the needs of the project.

The Materials List is as Follows:

- A sufficient number of temperature loggers to gather data at the desired depth intervals. GLKN currently uses HOBO Water Temp V2s. Other loggers may be used to meet the goals of the project, but follow manufacturer recommendations before deployment. There may be other loggers or multi-parameter sondes that can be used depending on needs and what research questions are being asked.
- A brass chain, long meter tape, or rope counter to accurately measure lines.
- Half-inch hollow-braid polypropylene line (or other appropriate line). You will need two lengths. One should be 2-3m longer than the expected water depth (e.g., in a 10-m lake, cut a line 12–13 m long); The second length is for a grab line that is at least 2 times the depth of the water at the site. This line is tough and floats in the water but does not hold knots well.
- One 1-lb. spool seaming twine; bonded nylon seine twine. This should be plenty for the construction of several arrays. This is used to splice/create loops in the polypropylene hollow core line.
- Fids (a tool used to separate strands of line; Figure 12) are used for splicing hollow core polypropylene line. The fid should be smaller than the diameter of your line, or a special tool called a fid pusher will be needed to move the fid through the hollow core line. For example, ¾-inch line requires a ½-inch fid.
- Plastic net needles (appropriate for the size of seaming twine), used for sewing twine while splicing hollow-core poly lines (Figure 13).
- 2-inch stainless steel quick links (6–10). It's nice to have extras; they come in handy for many purposes in the field.
- Hoop Net Swivels, size 11/0, 1500 lb. test (optional). One for the line, just above the anchor; one below the surface buoy on the instrument line. Two may be used on the vertical grab line, plus one above the anchor if using a two-line configuration. These are helpful to keep lines from twisting.



Figure 12. A 1/2-inch fid used for splicing 3/4-inch braided polypropylene line. If you don't have a fid, you can make one for 1/2-inch line using the tube from a Sharpie marker.



Figure 13. Net needle with seaming twine.

- Rope finder or grappling hook with a 3–6-foot length of 5/16-inch chain attached and a line at least 3× the depth of the water that the array is deployed in. The hook and chain attached to such a long line is critical to make sure the hook is in contact with the bottom of the lake to increase chances of hooking the grab line.
- Nylon parachute cord or polybraid line, approx. 1/8-inch in diameter.
- Zip ties; bring plenty. These are helpful for holding loggers close to the instrument line, strengthening splices, and may be handy for other purposes as well.
- Anchors. For backcountry lakes, use nylon mussel gathering bags filled with rocks gathered at the site. In some situations where disturbing rocks at the site would be unacceptable, other anchors may be more appropriate, such as concrete-filled buckets with eye-bolts for rope connection. Smaller anchor bags should be used for the grab line (sold as nylon bait or chum bags). If not using rocks from the site, chains or other heavy items such as window sash weights can be used. Do not use more anchor weight than you can safely handle from the boat. Ten to twenty pounds should be more than enough in most situations.
- Two PVC sponge buoys, for example 6×14-inch with 171 oz. (10.6 lbs.) of buoyancy. Other buoys may be used depending on project needs. You may want to use larger or smaller ones depending on your logistical needs. These come in different colors, and colors should be chosen based on the need for the array to be more or less visible.
 - For deployment in areas without motorboat traffic, spray paint one buoy (for on the surface) a dark color, so it is not obvious to visitors (flat black, or another color to match the surroundings; Figure 14).
 - If you expect motorboats in the areas, use a visible staff buoy with flags, reflectors (or lights), and bright colors to make sure that boats will not hit it (Figure 15). Make sure the paint you use will not dissolve the buoys. The underwater buoys can be left their natural colors, since they are difficult to spot underwater, and usually are covered in algal growth in a very short time. **Remember:** the amount of anchor weight you need is determined by the buoyancy of your buoys. If you order buoys that are too big, you may have to use more weight than is safe to handle from your boat.
- **Optional:** if you have access to the equipment, use an ultrasonic or radio telemetry tag near the surface to help with relocation in the spring.



Figure 14. Example of black array buoy meant to help the buoy visually blend with its surroundings when on a lake in designated wilderness. Siskiwit Lake, Isle Royale National Park.



Figure 15. Example of a high-visibility staff buoy that can be used in areas with motorboat traffic. The buoy in the picture was deployed as part of the array at Grand Sable Lake, Pictured Rocks National Lakeshore.

14.3.3 Construction

The array should be constructed on land. Use an open field, parking lot, or a lawn to lie out and measure your lines.

1. A brass chain, long meter tape, or rope counter should be used to measure the instrument line and the grab lines. The instrument line will need be as long as the water is deep, with the vertical grab line (if using one in a deeper lake) about 2 m shorter. The horizontal grab line needs to be at least two times the water depth, up to 50–100 m. Leave enough extra line on

the ends to account for buoy attachment, rope splicing, mistakes, or changes in water depth. Remember that you want the main instrument line about to be about 1.5–2 m shorter than the water depth to allow for deployment under the ice, and/or beneath boat propellers. Measure twice, cut once! Cut the lines to the proper length, either with a heated rope cutter or with a knife or sharp scissors. If you use a knife or scissors, be sure to singe the poly lines with a lighter or torch so that they won't unravel.

2. Braided poly line is very durable and floats, making it perfect for this application, but ties poor knots. As a result, you have to create loops to join this rope to anchors, buoys, and other lines. To accomplish this, tuck the end of the line into the fid (Figure 16). Compress the braid to allow the gaps between the braids to widen (Figure 16, A) so that the fid can be inserted into the hollow core of the line (Figure 16, B). Compress the line ahead of the fid as you push it further into the hollow core of the line (Figure 16, C). You may need a fid pusher (or a long, thin screwdriver) to push the fid further into the hollow core line (not pictured; see Shearer et al. 2015 for details). Push the fid into the hollow core until the loop at the end is the correct size (Figure 16, D); make sure that you have 12-16 inches into the line. Push the fid in between the braids of the line, and pull it out (Figure 16, E). Be sure to leave the bitter (tag) end of the line inside the hollow core of the line. Secure the splice using some seaming twine on a net needle by tying a series of half hitches and surgeon's knots around the line where the end of the line is inside the hollow core (Figure 16, F). This loop is the "bottom" of the array, where the anchor will be attached at deployment. It provides a starting point for placement of the loggers in step 4, below, in the case of the instrument line. In the case of both vertical lines, it may be a good idea to wait to trim and splice the other end until completing step 7, sub-surface buoy attachment. Remember, you want the top of each line 1–2 meters below the surface.
3. Horizontal grab line construction: Repeat the above step on both ends of the line that will be your horizontal grab line. This will result in a line that is at least twice as long as the projected water depth, with a loop at each end of the line.
4. Starting at the loop you created in the previous step, use a long meter tape or a brass chain to determine the placement of loggers and use a permanent marker to mark where they should be placed. This depends on the water depth, question being asked by the research as well as the number and type of loggers you have access to. Be sure to leave some excess on the top for attaching the buoy or plan to splice on additional line for attaching the buoy.
5. Cut the appropriate number of logger attachment lines plus several extras out of parachute cord or other appropriate smaller diameter line. The extras will come in handy in the field for tying anchor bags shut securely or for other purposes that will occur to you during deployment (e.g., strengthen attachment points for anchors). These should be cut 1.0 m in length, but slightly longer than this may be more appropriate, depending on the instruments you are using. Sear the ends so they don't unravel, or use a hot rope cutter. If attaching a multiparameter sonde or other large instruments, other methods will need to be explored and

additional buoys just above the instruments may need to be added to allow the line to stay straight in the water column.

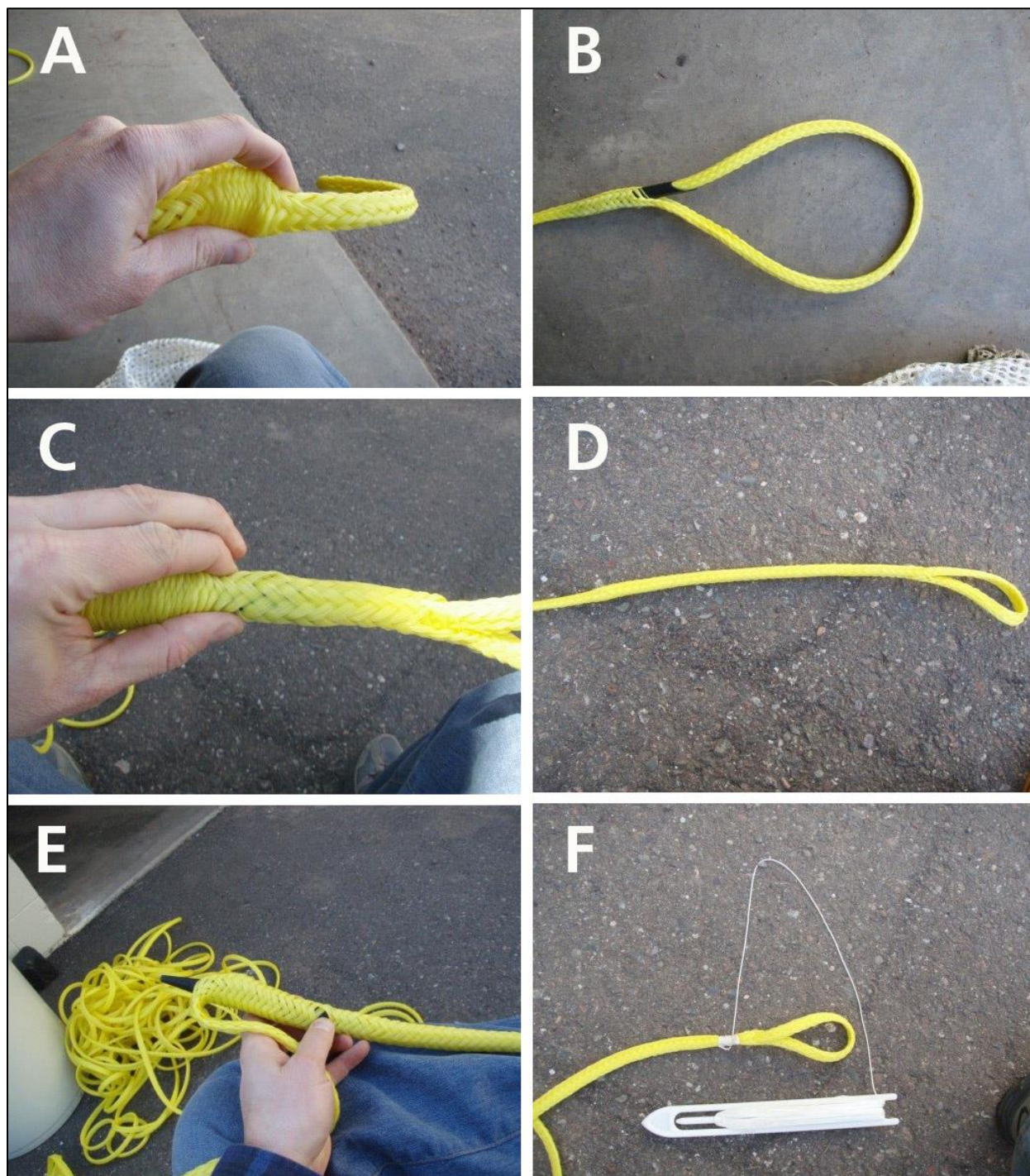


Figure 16. Procedure for creating loops to splice polypropylene hollow core line. Procedures are detailed in the text above.

6. The loggers are attached to the line via the parachute cords directly via knots (Figure 17). It is preferred to use knots; using metal clips to attach to the line should be avoided. In preliminary work, metal clips were found to be corroded after only a few months in the water, and we had low confidence in their ability to retain the instruments. Therefore, the use of metal clips was discontinued after only one season. The parachute cords should be woven into the instrument line braid, and tied with an overhand or figure eight knot to secure the parachute cord to the line. Next, slide the instrument onto the parachute cord and tie an overhand or figure eight knot into the cord to keep the instrument in place on the line. Next, the parachute cord is woven into the instrument line again, and a clove hitch with several half-hitches can be used to lock the parachute cord to the line. Finally, if there is excess line, weave the bitter ends of the cord into the instrument line. If desired, secure it inside the hollow core line by wrapping with seaming twine or zip ties around the instrument line over the woven-in cord. Repeat for each instrument, but bear in mind that the final placement of the uppermost instrument may need to be determined following sub-surface buoy attachment in the next step.



Figure 17. Parachute cord is used to attach a temperature logger to an instrument line. The end of the line is tucked into the hollow core instrument line (upper left), while a zip tie was affixed around the line to hold the end in place (not shown).

7. Attach the sub-surface buoy. Do this in a way so that the buoy sits the desired distance below the surface. The buoy attachment is critical, because this is what keeps the instruments suspended in place in the water column. With that in mind, the buoy can be attached in any way to the instrument line. The sub-surface buoy on most arrays is attached to the instrument line by passing the instrument line through the hole in the center of the buoy and then splicing the bitter end of the line into the center of the instrument line to create a large loop that accommodates the buoy. The uppermost instrument (1–2 m) should be attached to the line adjacent to the buoy; usually right on top on the flat side is easiest.

8. Cut a 3-meter-long poly line for the instrument line surface buoy. Create a splice as detailed above in step 1 for the bottom of the line. Attach the surface buoy to this short line using the same technique as in step 7. Attach your surface logger about 0.3 m down the line from the bottom of the surface buoy, so that it hangs just below the surface. Bear in mind that many of the HOBO instruments (Water Temp Pro V2) are designed to float, so you may need to attach a little weight to the line adjacent to the instrument to keep it from sitting on the surface (2–3 extra quick links should do) or insert some stainless bolts or threaded rod into the hollow core line. If using a surface instrument, it is recommended that the logger be deployed inside of a solar shield, such as a white PVC pipe with holes cut into it, to allow water flow.
9. If not done prior to construction, mark the instruments with the appropriate depth using a paint pen, permanent marker, or labeling tape. Launch each logger in the lab using a HOBO shuttle or base station, attached to a computer with the latest version of HOBOWare Pro software installed (see previous section). Make sure the clock on the computer you are using to launch is adjusted to the proper local time and date (or some other pre-determined time, such as GMT). Follow the manual for instructions on how to interface and launch the loggers. Re-name each logger as detailed in the logger launch section above for the approximate depth stratum and lake name that it will be deployed in HOBOWare Pro for ease of data management. The loggers should be set to log every hour. Do a delayed launch, at a pre-determined time and date of your choosing.
10. Putting it together: Attach a quick link to each loop that you previously made at the ends of the lines. Attach the quick links to each other with a hoop net swivel in between each to prevent line twisting. Attach the surface buoy line to the instrument line using a quick link and swivels, and the grab lines to the instrument line in a similar way. The single line array will have the grab line attached at the bottom of the instrument line. Practice attaching the anchor bags to make sure you have the appropriate hardware before heading into the field; the large one goes at the bottom of the instrument line, the small one on the grab line (Figure 18).



Figure 18. An array being assembled on land. The buoys are in the foreground and the anchor bags and grab line in the background. Please note, the subsurface buoy has not been attached yet, nor have the loggers. The subsurface buoy will be attached near the swivels and quick links in the foreground (indicated by red arrow).

14.3.4 Deployment

1. **Safety is of utmost concern! DO NOT WORK ALONE! At least two people should work together on deploying and retrieving arrays!** All personnel will review SOP #2: Training and Safety. All persons involved in the deployment of arrays will wear proper PFDs. It is recommended that workers involved with deployment will carry readily accessible knives or shears, so that if they become tangled in the lines, they can cut themselves free. All workers are aware of all their body parts in relation to the array lines (especially hands and feet)—never stand on lines, especially if anchors are being dropped or retrieved. Windy days (15 knots or greater) should be avoided when deploying the arrays to avoid excessive drift. If working from a canoe, use canoe stabilizers (Figure 19). When working off of a small boat,

distribute the weight and persons in the boat so as not to capsize it while working with the array off one side of the boat.



Figure 19. Canoe with stabilizers and PFDs prior to searching for the array on Lake Richie, Isle Royale National Park.

2. Site selection: Typically, arrays will be deployed at the deepest station of the lake to obtain a profile of the complete water column. If maximum depth is unknown, consider waiting to put the finishing touches on the array until after scouting a deployment location and obtaining an accurate depth measurement. It is a good idea to use a multiprobe on a cable or a plumb line attached to a measuring tape to obtain an accurate depth at the site and ensure that the vertical lines are the proper length rather than relying on sonar depth finders or bathymetric maps. If you will be collecting other water quality data on the day the array is deployed, you should do this before array deployment, as the array will likely disturb bottom sediments. If a benchmark exists at the lake where the array is to be deployed, a water level should be obtained to help track changes in array depth through the season.
3. Fill out a field data sheet with any profile data, or notes about the site. The sheet will also be used to record any data or other information about the deployment, including GPS points and landmarks, as well as dates and times of deployment.
4. Select rocks to put in anchor bags, or attach anchors that you brought with you for this purpose. For the vertical lines, don't use any more weight than you need to keep the array in place and keep the subsurface buoys underwater. Make sure it is something you can reasonably lift without capsizing the boat or causing injury to persons working on the array—10–20 lbs. should be more than enough weight. If you are not sure, do some tests beforehand in shallow water to determine the appropriate anchor weight needed to submerge buoys. On the single vertical line configuration, use a rock that only weighs 2–3 pounds on the horizontal grab line. Attach the larger anchor bag with the rocks inside to the instrument line (large) and the smaller one to the grab line.

5. Assembly: The final assembly of the array components should be done on shore after scouting the deployment site.
6. Before deploying the array: temporarily attach a short length (2–3 m) of the floating line to the top of the surface buoy just in case the surface buoy sinks below the surface during deployment due to inaccurate depths or soft sediment. This will allow the array to be recovered so length adjustments can be made. Make sure that the line can be removed quickly without lifting the buoy back into the boat.
7. Grab line deployment. At this point, the whole array should be assembled. The grab line will hold you on your station (more or less) while you deploy the instrument line. Carefully pile the lines with the buoy on the bottom and the end of the rope that will attach to the anchor on top. Attach the anchor and make sure all persons and equipment are clear of the grab line. 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.** The GPS point should be collected on a GPS unit and recorded on a field sheet. 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 (Figure 20, *top*) because you have not yet begun to lower the instrument line (with anchor attached).
8. Instrument line deployment. **DO NOT THROW IT!** Lower the anchor down slowly in a controlled manner, being careful to not knock the loggers on the side of the boat as the line goes out (Figure 20, *bottom*). As you lower the anchor attached to the instrument line, 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, 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 (Figure 21). **Immediately collect a GPS point on a GPS unit** and record on a field sheet. Make notes about and photograph landmarks that could help you locate and retrieve the array, especially if this is an initial deployment.
9. Adjust the depth of the instrument line so that the upper-most instruments below the surface are at or near the depth you have assigned to it. This can be checked by attaching a small weight, such as a plumb line to a fiberglass tape measuring the distance from the water surface to the top of the subsurface buoy (Figure 22). A stiff tape measure with a weight attached, brass chain, or a long plumber's ruler (a folding ruler) can be used to check depth as well. If you adjust the distance between the sub-surface buoy and the next logger below, be sure to note the change in distance between the two, and keep track of the actual depth of the loggers throughout the season. If you have to lengthen the line and add another logger, be sure to note this as well.



Figure 20. Instrument line deployment 1. (*Top*) The grab line has been deployed (trailing off to the upper left underwater) and the instrument line anchor is about to be released. The instrument line and buoy are coiled forward of the canoe thwart. (*Bottom*) The line is being lowered slowly, and care is being taken to not hit the loggers on the side of the boat. The instrument line anchor is about 2 m off the bottom in this photo. The white buoy is the sub-surface buoy.



Figure 21. Instrument line deployment 2. 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). The line between the buoys should be about 2.5 m long, for a sub-surface buoy that is to be deployed 1.5 m under the water. The yellow line attached to the right side of the black buoy is an extra length (about 3 m) of line attached to the surface buoy for easy retrieval, just in case the instrument line was too short and sunk the surface buoy.



Figure 22. Instrument line deployment 3. Measuring the distance of the subsurface buoy underwater, after array placement.

10. If it is early in the season, you can adjust the length of the line during maintenance trips, if needed. If it is too long, you can gather the bottom of the line to shorten it and secure it with seaming twine or with extra lengths of parachute cord. This way, if water level goes up, you can remove the twine to adjust the depth. If the line is too short, splice on an appropriate length of poly line, preferably at the bottom of the array, and add a logger, if desired. Just be

sure that if you expect ice before the next time you return, make sure it is at least a meter below the surface, or more depending on boat traffic (Figure 23).



Figure 23. The surface and sub-surface buoys following deployment on a non-motorized lake. The sub-surface buoy is about a meter below the surface.

11. Check that the surface logger is slightly below the surface (0.1–0.3 m). Many instruments naturally float, so you may need to attach the body of the logger to the line with a zip-tie or length of parachute cord. You may also need to attach a quick link or similar small weight to the line adjacent to the logger to make certain that the logger will stay underwater during extended deployment. Also be sure to use a solar shield, such as a length of white PVC pipe, to make sure the instrument is collecting water temperature and is not exposed to direct sunlight.

14.3.5 Array Recovery and Maintenance

14.3.5.1 Equipment Needs

- A field data sheet. The sheet will be used to record date and time of recovery, any field data collected, and any notes about the recovery and re-deployment.
- Grappling hook with chain and line. If recovering an array without a surface buoy, a grappling hook is needed to hook the grab line and bring the instrument line to the surface. Grappling hooks should be made of strong steel. They are sold as “rope finders” through commercial fishing supply companies and come in a variety of weights. It is important in array recovery to make sure that the grappling hook is in contact with the bottom. **If the hook is not in contact with the bottom, it is unlikely that the array will be recovered.** Therefore, a line used in array recovery should be at least 1.5× the water depth. In addition to using a sufficient length of rope, it is suggested that 1–2 m of 8-mm (5/16-inch) chain be attached between the grappling hook and line. The weight of the chain and the hook, should

probably not exceed 8–9 kg (15–20 pounds), unless working in very deep water and using a motorboat.

- GPS. A GPS with the most recent coordinates for the array will greatly assist in locating the array. It is advised to create a point 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 on the GPS before leaving the office. Without a GPS, landmarks may be used to locate the array, but this will likely increase the time needed to locate the array.
- Shuttle or other download equipment needed to communicate with loggers. Typically, GLKN uses the Onset U-DTW-1HOB0 shuttle to offload all HOB0 loggers. Other types of equipment, such as multiparameter sondes, may require a laptop computer loaded with appropriate software to recover data. Be sure to plan accordingly to ensure proper function of shuttle or other equipment.
 - Before leaving to visit the array to download data, install shuttle batteries, save all data already on the shuttle, update shuttle firmware, and sync it with a computer that is set to the correct time/date. Make sure that the shuttle batteries have enough power to finish downloading all data. Failure to complete these steps can contribute to data loss.
- Multiparameter sonde. It is desirable to collect a profile of the water column at the site prior to array recovery. In case of array failure, this data will become important, and will be useful in QA/QC of array data.
- Boat or canoe. Be sure to use an appropriate boat or canoe for the work being accomplished, and follow all requirements of maintenance and safety equipment required for the boat/waters you are working on. All staff will wear a PFD and will have pertinent watercraft training. If using a canoe, it is strongly recommended that canoe stabilizers be used to prevent capsizing.

14.3.5.2 Recovery and Maintenance

1. Navigate to the site of the array using a GPS. If the surface buoy is attached, pick up the instrument line directly. If recovering the array after the winter or the surface buoy is not attached, use the GPS to navigate to the location between the anchor bag and instrument line GPS points. This should allow the grab line to be hooked if the grappling hook is dragged perpendicular across the grab line. Paddle or motor VERY SLOWLY to ensure that the hook is contacting bottom while “trolling” with the grappling hook. It may be helpful to attach one end of the line to the boat to ensure that the line is not lost. Make sure you have enough line out (1.5×–3× the water depth). If recovering the array with a grappling hook, it is advisable to only lift with the grappling hook line until the sub-surface buoy reaches the surface of the water; then grab the line at the buoy and continue lifting the instrument line. Especially in a motorboat, make sure you have enough weight out that you are constantly in contact with the bottom. 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. If this does not work, you can try circling the GPS points while dragging the grappling hook.

2. Once the grab line is hooked, pull the whole instrument line into the boat up to the anchor. If removing the array from the water, simply pull the all the lines into the boat. If downloading and redeploying the array, one person can hold the instrument line to prevent the anchor from dropping, or attach the line to a cleat if using a larger boat, but avoid moving the anchor attached to the grab line (optional; it may be desirable to remove the whole array before cleaning and preparing for re-deployment, depending on conditions in the field and crew members). The other crew member should clean loggers with rags to facilitate download using the shuttle.
3. Download data following logger/shuttle instructions. Check all hardware, knots, and splices as you go. Repair/replace ones that appear suspect.
4. After downloading a logger, slowly lower the line back in the water, one logger at a time. Repeat until all loggers have been downloaded and the anchor is back on the bottom.
5. Adjust buoy and line depths, as needed. Follow steps in the deployment section. **ALWAYS** re-GPS the array (as described in the deployment sections) and note any changes of location or depth.
6. Immediately upon returning to the office, download the shuttle to your PC and check the integrity of the data you collected. If there appears to have been a problem, you may have to go back and re-launch the loggers, or replace loggers. This can be caused by shuttle firmware problems, or failure to sync a shuttle after changing batteries. If it is possible to bring a laptop in the field, it can be checked before leaving the site.
7. When finished with the shuttle for more than a few days, remove the batteries, as the shuttle has a tendency to turn on when stored close to the couplers and run down batteries. (It operates via magnetic switch—the couplers have magnets designed to engage the switch.) Also, batteries left in the shuttle for a long time have a propensity to leak and may damage the circuit boards inside the shuttle.

14.4 Data Management

General data management practices follow those shown in SOP #8, Data Management. The following sections outline specific data management steps while using HOBOWare or Aquarius for continuously-collected water temperature data.

14.4.1 Formatting .CSV files generated in HOBOWare for import into Aquarius

Aquarius can import proprietary data formats generated by many types of data loggers, such as YSI.dat for example, but NOT files with the .HOBO extension. These files must be saved as one of the “flat” file formats, typically a .CSV file. HOBOWare allows logger files to be batch processed from .HOBO files to .CSV files quickly. Before converting the .HOBO files, make sure that the raw data files are stored for archival purposes in the designated location as determined by the project manager, where they will be periodically backed up with all other GLKN water quality data.

After storing the raw files for archival purposes, convert the files to .CSV. Open HOBOWare, and click on Tools > Bulk File Export > Select Files to Export (Figure 24). Navigate to where the .HOBO files you want to export into .CSV are stored. Select all files you are interested in (Figure 25). Click “Continue”. On the next screen, you will need to navigate to where you want to store the .CSV files, and then click “Export”. The bulk export will then run. When it tells you it has finished, click OK. The .CSV files should now be where you told the software to store them.



Figure 24. Accessing the bulk file export tool in HOBOWare. Click on “Tools” (circled), then “Bulk File Export”, and then “Select Files to Export” to choose which .HOBO files will be converted to .CSV to allow importation into Aquarius Springboard.

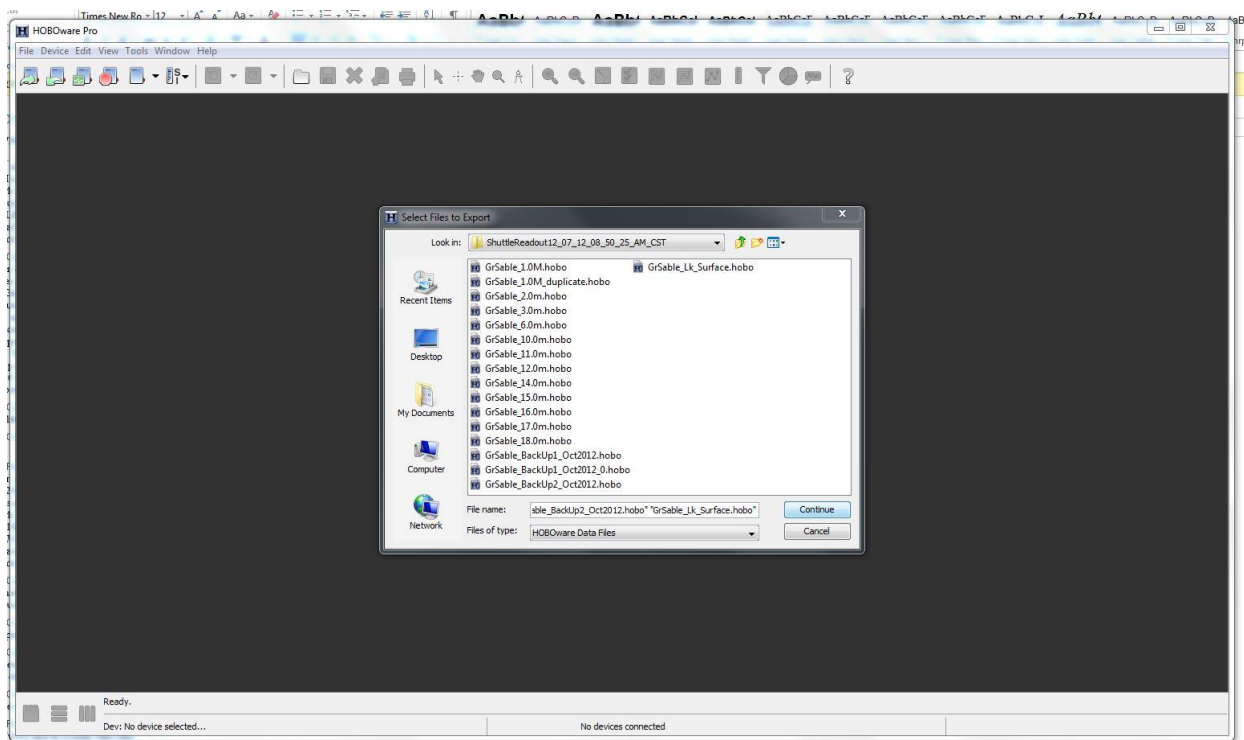


Figure 25. Hold the control key and click each of the .HOBO files you want to export to .CSV. Then click "Continue".

If the instructions on setting up HOBOWare and launching logger were followed in the prior section, nothing will need to be done to the files. The files should look like Figure 26, if they are opened in Excel. If they do not, delete any columns to the left of "Date Time" (GLKN's Aquarius import configuration specifies that the date to be the left-most column), and delete anything above the header row. Any columns to the left of the data (in this case, the columns that the logger saves to show when loggers were started, stopped, offloaded, etc.) can simply be skipped upon import to Aquarius Springboard. A text editor can be used to view these files as well.

If you must open the .CSV files to alter them in Excel, make sure to click "Save As" before closing them and saving them as "CSV (comma delimited)" (Figure 27). Failing to do this will result in the file being saved as Unicode Text (*.txt) which will result in extra steps to make the file useable in Aquarius Springboard.

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	Date Time, GMT-(Temp, °C (Batt, V (LC Coupler D Coupler A Stopped (End Of File (LGR S/N: 2411272, SEN S/N: 2411272)												
2	4/10/2012 22:00	19.032	3.57	Logged									
3	4/10/2012 23:00	18.533	3.57										
4	4/11/2012 0:00	18.39	3.57										
5	4/11/2012 1:00	18.438	3.57										
6	4/11/2012 2:00	18.509	3.57										
7	4/11/2012 3:00	18.604	3.57										
8	4/11/2012 4:00	18.699	3.57										
9	4/11/2012 5:00	18.771	3.57										
10	4/11/2012 6:00	18.818	3.57										
11	4/11/2012 7:00	18.414	3.54										
12	4/11/2012 8:00	12.34	3.54										
13	4/11/2012 9:00	11.662	3.54										
14	4/11/2012 10:00	11.929	3.54										
15	4/11/2012 11:00	9.558	3.57										
16	4/11/2012 12:00	7.895	3.57										
17	4/11/2012 13:00	9.064	3.57										
18	4/11/2012 14:00	9.534	3.57										
19	4/11/2012 15:00	8.319	3.57										
20	4/11/2012 16:00	5.154	3.54										
21	4/11/2012 17:00	5.154	3.54										
22	4/11/2012 18:00	5.128	3.54										

Figure 26. What a .CSV file converted from a .HOBOT should look like before being imported into Aquarius Springboard, when opened in Excel.

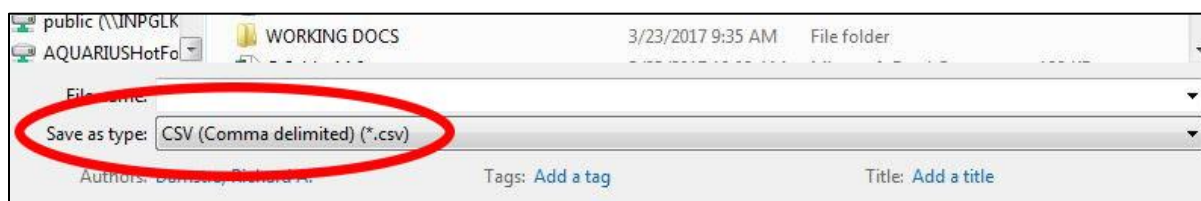


Figure 27. Screenshot showing how to save an edited .CSV file in Excel.

14.4.2 Importing .CSV Files into Aquarius Springboard

Aquarius is a powerful program and has more functionality than can be detailed here. For detailed instructions on how to use Aquarius Springboard, please visit <https://nrss.sharepoint.nps.gov/div/wrd/data/Pages/AquariusNG.aspx>. Materials on how to use the latest version of Aquarius tailored to NPS users can be found at the link. Here, the focus is on what

specific information (data and metadata) need to be added during creation of locations within Aquarius to ensure consistency between datasets managed by GLKN.

Before any data can be added, a location and time series data set container must already exist in Aquarius or be created to house the data. If you are adding a new array you will have to take the following steps:

- 1.) In Aquarius Springboard, click on the Location Manager icon, or click, and select “New Location”.
- 2.) Populate the location information (metadata). For an example of completed site metadata, see Figure 28.
 - a. Fill in the identifier for the site. Typically, these take the format “Data Owner_PARK_###”. For example, an array deployed by GLKN at Lake Richie at Isle Royale has the location identifier “GLKN_ISRO_03”. Whenever possible, use existing Site IDs, as outlined in the protocol narrative. If a site does not already have a Site ID, consult with the water quality program manager to create one.
 - b. Fill in the Site Name that is most typically used by NPS Staff.
 - c. Select a “type” from the drop-down. In our case, typically, this will be “Lake”.
 - d. Fill in the latitude and longitude. These are needed for the data to appear on the map in Aquarius Web Portal.
 - e. Pick the appropriate time zone for the location of the park, and/or matches the time zone of the loggers.
 - f. Pick park name from the drop-down.
 - g. For Sensitivity, choose “NPS Only” to start, this will only allow NPS staff to view the data. When you are ready to display the data on the web portal, you will change the data to “Public”.
 - h. Choose a Status. Mostly, these will be active. If an array is removed from a lake, the site may be marked as inactive or retired.
 - i. Fill out the other info as appropriate, with waterbody (HUC) code, a waterbody name (if different than the Name above), date established, and travel directions.
 - j. Finally, leave the check box next to “Make Location Visible in Aquarius WebPortal” unchecked for now. When you are finished creating the site, adding data, and performing QA/QC checks on the data, you will have to remember to go back in and check this box.

The screenshot shows the 'GLKN_ISRO_03 - Lake Richie' form in the Aquarius Location Manager. The form includes fields for Identifier, Name, Type, Source, Description, Position (checked), Geo Datum, Latitude, Longitude, Elevation, Time Zone, and Additional Attributes. The Additional Attributes section includes Park Name, Sensitivity, Status, Waterbody Code, Waterbody Name, Gage Number, Date Established, Travel Directions, and a checkbox for 'Make Location Visible in Aquarius WebPortal'.

Identifier:	GLKN_ISRO_03		
Name:	Lake Richie		
Type:	Lake		
Source:	AQUARIUS Location		
Description:	Moored temperature array site at Lake Richie; co-located with water quality index site location		
☒ Position:	Geo Datum:	WGS 84	
	Latitude:	48.0410454	Longitude: -88.7005398
	Elevation:	628	ft
Time Zone:	EDT (UTC-04:00)		
Additional Attributes:			
Park Name:	Isle Royale National Park		
Sensitivity:	Public		
Status:	Active		
Waterbody Code:	04020300		
Waterbody Name:	Lake Richie		
Gage Number:			
Date Established:	05/28/2010		
Travel Directions:	Dock at Moskey Basin Campground and portage to Lake Richie. Canoe to site near Lake Richie Canoe Campground		
Make Location Visible in Aquarius WebPortal:	☒		

Figure 28. Example of time series with completed data in Aquarius Location Manager.

Now that you have created the location, you will create a new time series data set container that you will populate with the data in the .CSV file. Take the following steps:

1. Click on the “Data Sets” tab.
2. Then, Click on the “New” tab, open the drop-down and select the time series type. Most of the time, you will select “Time Series-Basic” for a logger file. If you are importing data from a discrete visit, you will pick “Time Series-Field Visit”.
3. Fill in the data that will describe the time series. See Figures 29 and 30 for an example of the information added to a completed dataset.
 - a. It is easier to pick the parameter that the time series represents under the “data” section. Pick the parameter from the drop-down. For an array it will usually be temperature or depth. Be sure to pick the proper units. Parameters that have been used before will show up in the drop-down, usually with proper units assigned.
 - b. If the parameters are not in the drop-down, you will have to click on the ellipsis “...” at the end of parameter box and pick the appropriate parameter from the list.

- c. Look down to the “Gaps” section. Fill in the “Gap Tolerance (mins)”. This is the amount of time that is allowed between points in a time series before the system identifies a gap in the data. Generally, the gap tolerance should be set slightly longer than the normal time between samples. For example, if loggers are collecting data every 60 minutes, set your gap tolerance for 61 minutes.
 - d. Go back up to the “General” section. Fill in the “Label” blank. For an array, typically, the label will follow the format: “Depth m _Temp_Array_Logger Serial #”. For instance, the label for a temperature logger at 10 m on an array at Mukooda Lake at VOYA with the serial number 1005914 would have the label: “10.0m_Temp_Array_1005914” (Figure 29). Depth logger formats are similar; for example, a depth logger with the serial number 2001999 at Bass Lake at SLBE would have the format “8.0m_pressure_array_2001999” (Figure 30).
 - e. You will notice as you fill in the label, the “Identifier” blank populates with information from the label and already has the parameter and the site ID there.
 - f. Fill in an appropriate description, such as “water temperature @10m nominal depth”
 - g. Fill in an appropriate comment.
 - h. Click the “Yes” radio button next to Publish if you want to allow approved data from the time series data set to be accessible to the public in the Aquarius WebPortal.
4. Repeat steps 1 through 3 for each remaining logger for the location.

Data Set Details			
General			
Type:	Time Series - Basic		
Identifier:	Water Temp.10.0m_temp_array_1005914@GLKN_VOYA_22		
Label:	10.0m_temp_array_1005914		
Description:	array water temp @ 10m nominal depth		
Comment:	10m water temperature on moored temperature array		
Publish:	☒ Yes ☐ No		
Data			
Parameter:	Water Temp		
Units:	°C		
Time Zone:	CDT (UTC-05:00)		
Gaps			
Gap Tolerance (mins):	61		
Total Gaps:	1		
Statistics			
Start Time:	2012-07-12 11:00:00		
End Time:	2016-07-28 12:00:00		
Min:	0.00	Mean:	5.42
Max:	33.18	Total Samples:	35451
Start Value:	28.00	End Value:	23.35
Sampling Rate:	0.00		

Figure 29. Example of completed metadata for a single time series for a temperature logger.

Data Set Details			
General			
Type:	Time Series - Basic		
Identifier:	Absolute Pressure.1.5m_pressure_array_9800749@GLKN_PIRO_01		
Label:	1.5m_pressure_array_9800749		
Description:	Abs. Pressure with Hobo U-20 temp/pressure logger		
Comment:			
Publish:	☒ Yes ☐ No		
Data			
Parameter:	Absolute Pressure		
Units:	kPa		
Time Zone:	EDT (UTC-04:00)		
Gaps			
Gap Tolerance (mins):	61		
Total Gaps:	11		
Statistics			
Start Time:	2012-04-10 22:00:00		
End Time:	2018-09-11 12:00:00		
Min:	0.00	Mean:	117.25
Max:	188.93	Total Samples:	68325
Start Value:	99.41	End Value:	105.63
Sampling Rate:	0.00		

Figure 30. Example of completed metadata for a single time series for a Pressure (depth) logger.

Now data must be appended into the time series data set container. To append data to the data sets, follow the guidance at: <https://nrss.sharepoint.nps.gov/div/wrd/data/Pages/AquariusNG.aspx>

14.4.3 Data QA/QC

14.4.3.1 General Principles

Aquarius has extensive tools for QA/QC of continuous data. A comprehensive “How-To” is outside the scope of this document. For specifics on how to use the QA/QC toolbox in Aquarius, please see <https://nrss.sharepoint.nps.gov/div/wrd/data/Pages/AquariusNG.aspx> Here we will focus on what measures to use to ensure good data, and a general workflow.

14.4.3.2 Typical Data QA/QC

Most QA/QC of data in Aquarius will consist of removing out-of-water data points from the corrected time series when the array recorded air temperature data prior to deployment, during maintenance, and/or after retrieval (Figure 31). Occasionally, loggers will record erroneous data, and when values are too high or low to make sense, they can be removed from the corrected time series. These values are often approaching 100°C or are negative numbers, and are obvious in the context of the rest of the data. These issues are usually caused by data corruption due to dirty logger or shuttle windows, or may be caused by exposure to bright sunlight during data transfer with the HOBO Optical Shuttle. Low logger battery voltage may also cause data corruption or loss, but this is relatively rare if loggers are removed from the field and exchanged with new loggers on a schedule based on the battery life of the loggers (in the case of HOBO Water Temp Pro V2 on GLKN lakes, this is no longer than five years).

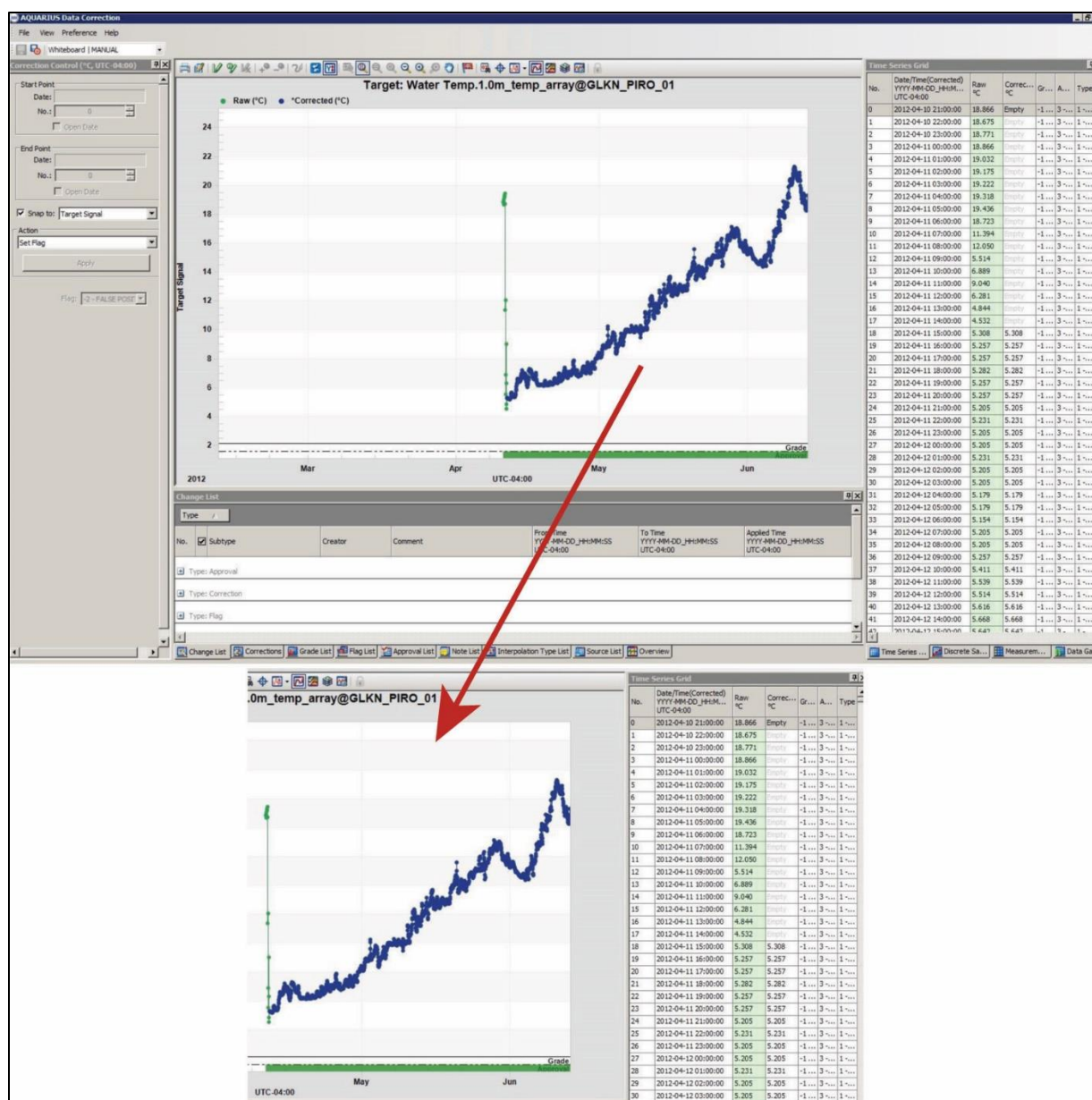


Figure 31. An example of data from an array deployment where data were collected out of the water prior to the array being deployed. The deleted data from when the logger was out of the water are shown in green in the chart and as empty cells in the Corrected data column in the table.

For the most part, out of the water data will be eliminated from the corrected time series by looking at field notes and identifying dates and times where the array was serviced. This data will be selected and be eliminated from the corrected time series using the “Delete Region” action under “Correction Control” so it is excluded from future analysis. A similar technique is used for corrupted data, which is typically easy to recognize visually, due to the usually extreme nature of the corrupted data.

An alternate method to find these outliers is to use the “Rate of Change” option “Threshold Correction/Flagging” action under Correction Control, to flag data that undergoes a rapid rise or

rapid fall of 4°C per hour. Additionally, the Correction Control can be used to flag data below -1°C and above 30°C, as these extreme temperatures likely represent corrupted data or out-of-water data. After this is completed, each of the flags created will have to be examined to determine if the flagged points will need to be deleted, or if the data will need to be flagged for later examination, and eliminated as needed.

No interpolation will be allowed to close the data gaps caused by these data deletions. In most cases, the deletions result in a gap of only a few hours, which is insignificant considering the large volume of data collected by each array. If several weeks of data are missing, and a suitable surrogate data set exists for the same depth of the missing data location, it may be used to close the data gap. This situation will be rare, since instruments are rarely doubled up at the same depth on an array.

14.4.3.3 Data Approvals

Data must be approved by the project manager, or someone designated by the project manager, before the data can be released to Aquarius Webportal. Typically, once the data is corrected, it can be approved. Data approvals are also done in the Data Correction toolbox by selecting the newly corrected data in the approval tool and picking “3-Approved” from the drop-down list. For details, see <https://nrss.sharepoint.nps.gov/div/wrd/data/Pages/AquariusNG.aspx>.

14.4.4 Data Analysis

14.4.4.1 Creation of Estimated Instrument Depth Time Series

Air pressure and water pressure data can be used to calculate estimated depth of the pressure sensor in the water. This data is useful for tracking changes in depth that may explain shifts in temperature time series following array redeployment, or changes driven by fluctuating water levels from precipitation or other factors such as beaver activity.

Calculate water level using the following equation:

$$\text{Estimated instrument depth (m)} = [\text{Reference Pressure (kPa)} - \text{Water Pressure (kPa)}] * 0.101972$$

where 0.101972 is the depth of water in meters that equals 1 kPa of pressure.

Create a calculated derived time series in the Location Manager in Aquarius Springboard (Figure 32). Fill out the data set details as shown in Figure 33. Set the parameter to “DepthFromWaterPressure”, the units are set to meters, and that the time zone is set to the local time zone. Select the pressure time series as the inputs.

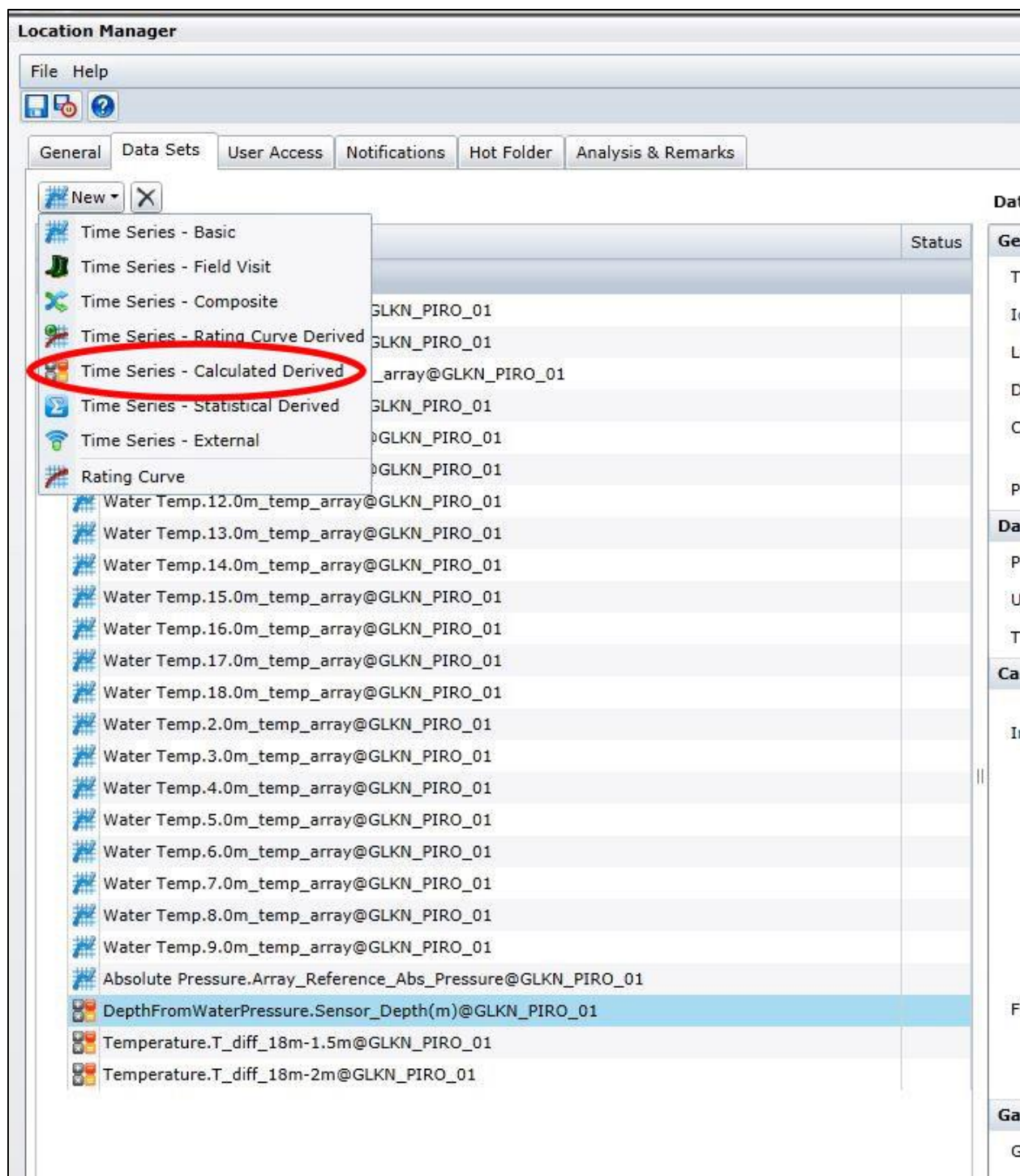


Figure 32. Creating a calculated derived time series in Aquarius.

Data Set Details										
Status	General Type: Time Series - Calculated Derived Identifier: DepthFromWaterPressure.Sensor_Depth(m)@GLKN_PIRO_01 Label: Sensor_Depth(m) Description: Depth in meters derived from pressure Hobo U-20 Temp/Depth Loggers deployed at approximately 1.5m and on shore nearby Comment: NPS ONLY Publish: ☐ Yes ☒ No									
	Data Parameter: DepthFromWaterPressure Units: m Time Zone: EDT (UTC-04:00)									
	Calculation <table border="1"> <thead> <tr> <th>Inputs:</th> <th>Name</th> <th>Value</th> </tr> </thead> <tbody> <tr> <td>x1</td> <td>Absolute Pressure.1.5m_pressure_array@GLKN_PIRO_01</td> <td></td> </tr> <tr> <td>x2</td> <td>Absolute Pressure.Array_Reference_Abs_Pressure@GLKN_PIRO_01</td> <td></td> </tr> </tbody> </table> Write a formula for y in terms of x1 and x2: eg. $y = x1 + \log(x1)$; $y = (x1 + x2) / 2$ Formula: $y = (x2 - x1) * 0.101972$  This formula is valid. Validate	Inputs:	Name	Value	x1	Absolute Pressure.1.5m_pressure_array@GLKN_PIRO_01		x2	Absolute Pressure.Array_Reference_Abs_Pressure@GLKN_PIRO_01	
	Inputs:	Name	Value							
	x1	Absolute Pressure.1.5m_pressure_array@GLKN_PIRO_01								
	x2	Absolute Pressure.Array_Reference_Abs_Pressure@GLKN_PIRO_01								
	Gaps Gap Tolerance (mins): 61 Total Gaps: 5									
	Statistics Start Time: 2012-04-10 22:00:00 End Time: 2016-11-25 08:52:11 Min: -2.34 Mean: -1.33									

Figure 33. Data set details for a calculated derived time series for depth.

14.4.4.2 Ice Duration

Ice duration is an important driver of lake ecology. As the climate changes, we expect changes in ice duration and phenology (Pierson et al. 2011, Edlund et al. 2014, Pierson et al. 2016). When ice is present, a lake will typically undergo inverse stratification. Inverse stratification is when temperatures at or near the surface are at or near 0°C, and are colder than the warmer water at the bottom of the lake (Wetzel 2001). Ice duration can be estimated using the algorithm from Pierson et al. (2011). This algorithm is simple; ice is assumed to be present when the lake is inversely stratified, and the difference in temperature between the top and bottom sensors is greater than 0.1°C (Pierson et al. 2011). The algorithm can be created as a calculated derived time series similar to the depth estimates in the section above. Alternatively, inverse stratification and ice cover can be interpolated from a graph of temperature from near the surface and near bottom (Figure 34).

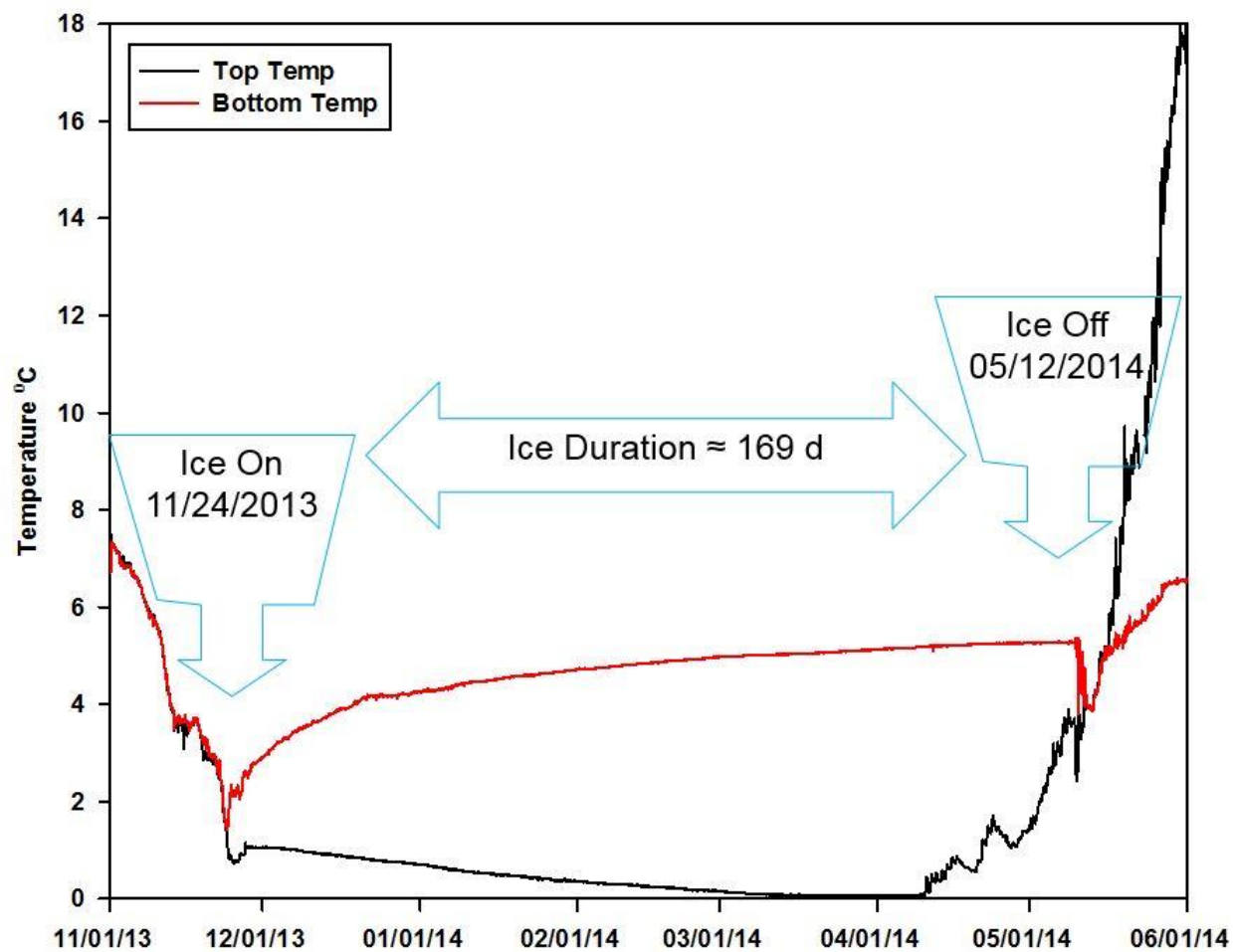


Figure 34. Interpolation of inverse stratification and duration of ice cover during winter of 2013–2014 at Lake Richie, Isle Royale National Park.

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