AOS PROTOCOL AND PROCEDURE: BATHYMETRY AND MORPHOLOGY OF LAKES AND NON-WADEABLE STREAMS

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Change Record

REVISION	DATE	ECO #	DESCRIPTION OF CHANGE
A	06/02/2014	ECO-01129	Initial release
B	01/26/2015	ECO-02636	Migration to new protocol template
C	08/27/2015	ECO-03158	Updates for clarification, added figures.
D	02/29/2016	ECO-03680	Updates for clarification, and edits based on technician review; added figures.

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1 OVERVIEW

1.1 Background

Bathymetry and morphology are key parameters for defining the hydrological, physical, chemical, and biological characteristics of lakes and non-wadeable streams. Water level, volume, area, and stage curve relationships provide spatial quantitative information. They also impart a governing role on hydrodynamics, chemical reactions and biotic distribution and productivity. Furthermore, temporal comparisons between bathymetries can be used as an indicator of environmental change by providing information on ecosystem functioning, changes in water turnover times and storage, and catchment erosion-sedimentation rates (Dost and Mannaerts, 2008). Obtaining baseline characteristics, hence, becomes imperative in light of future activities aimed at a better understanding of lake dynamics and health through time.

High accuracy depth (bathymetric) maps are obtained using a suite of hydroacoustic instrumentation interfaced with a differential global positioning system (DGPS) mounted on a vessel. The Wide Area Augmentation System (WAAS) is a form of DGPS that provides enhanced position accuracy (<3 m). Hydroacoustics are utilized to detect the depth of a water body, sediment characteristics as well as the presence or absence, approximate abundance, distribution, size, and behavior of underwater biota. Measurements of depth and morphology are undertaken using an echo sounder transducer, and side scan sonar. Images of sediment and structures are obtained with Side Imaging® Sonar and Down™ Imaging offered as an integrated unit in the HumminBird 1198c Si Combo. High accuracy depth data can be obtained with a lower beam angle and higher frequency (>200 kHz) echosounder. The side and down imaging features enable the identification of water bottom sediment morphological features that can be used to better elucidate spatio-temporal hydrodynamics that may impact biological activity (Hofmann et al., 2008; Donohue and Molinos, 2009).

The sampling strategy involves bisecting the water body along its longest axis, then subsequent continuous transects are conducted parallel and perpendicular to this initial transect along the longest axis (Figure 1a lakes and Figure 1b non-wadeable streams). The instrumentation collects coordinate positions with an accuracy of less than 3 meters and depths simultaneously. The combined unit provides a high resolution and precision survey of the complex bathymetry and morphology of lakes and non-wadeable streams.

The data collected in the field is in x, y and z format – Eastings, Northings and Depth. Following quality assurance and quality control directives (RD [08]), data are spatially interpolated and clipped to the shoreline shapefile to produce 2D and 3D bathymetric maps. Bottom morphometric characteristics, such as vegetation extent, sediment characteristics, and sediment compaction are defined by converting the side-scan images into a master mosaic image of the waterbody bottom (Figure 2). Information about volume, surface area, and stage curves (relationship of gage height and stream discharge) are then calculated. The maps are used to calculate mean and maximum water depths along with shoreline and sediment morphometry. Additional information that the bathymetric maps can provide is an estimate of the depths and area of which plants can colonize. Water surface morphometric characteristics (shape and shoreline development index) can be used to calculate fetch distances. This protocol describes the steps required to collect data for the creation of bathymetric and morphological maps utilizing an acoustic system.

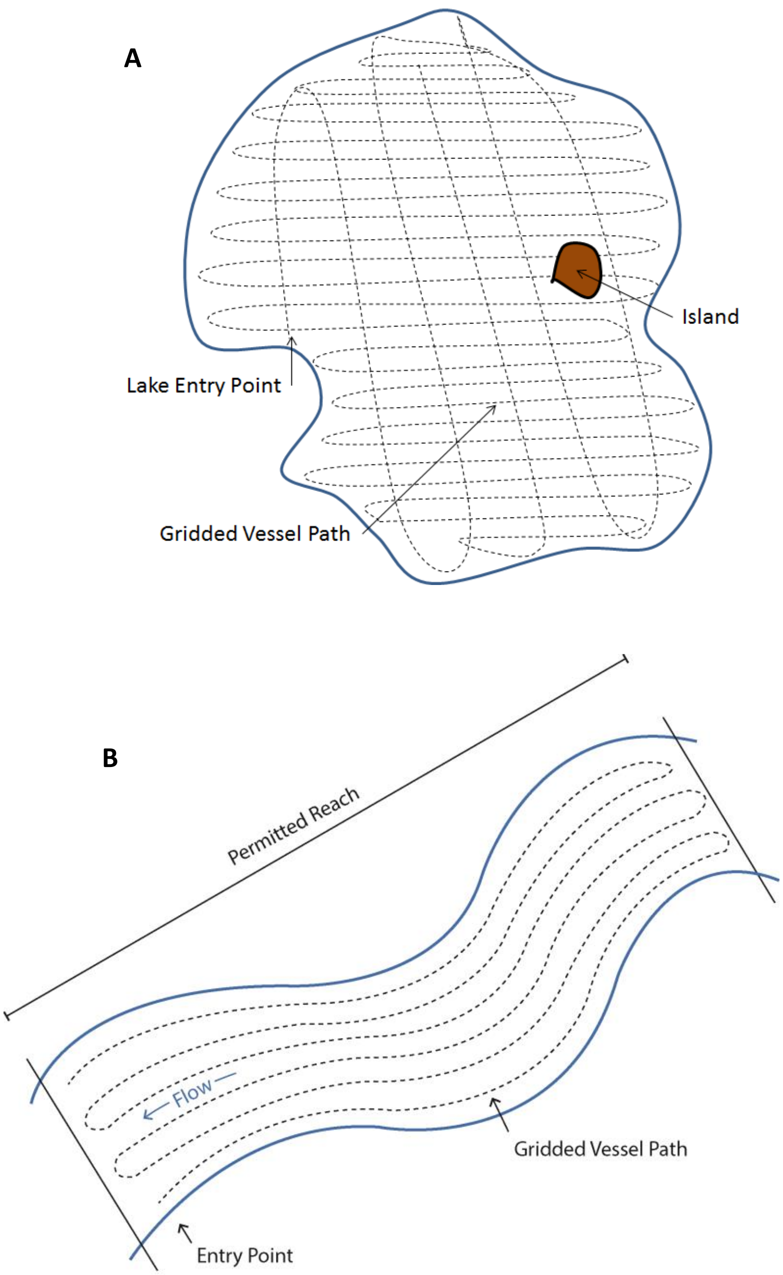


Figure 1. Grid pattern used for determining the (A) lake and (B) non-wadeable bathymetry and morphology

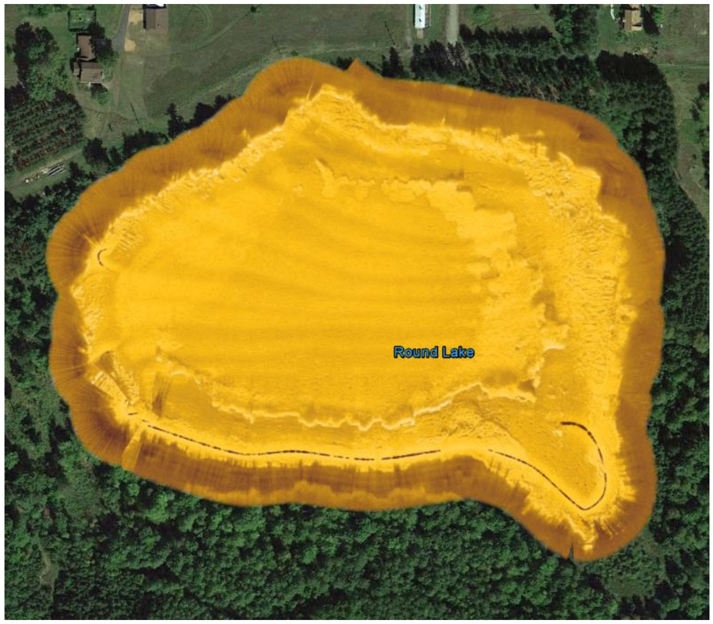


Figure 2. Example of side-scan mosaic master image of a lake bottom.

1.2 Scope

This document provides a change-controlled version of Observatory protocols and procedures. Documentation of content changes (i.e. changes in particular tasks or safety practices) will occur via this change-controlled document, not through field manuals or training materials.

1.2.1 NEON Science Requirements and Data Products

This protocol fulfills Observatory science requirements that reside in NEON's Dynamic Object-Oriented Requirements System (DOORS). Copies of approved science requirements have been exported from DOORS and are available in NEON's document repository, or upon request.

Execution of this protocol procures samples and/or generates raw data satisfying NEON Observatory scientific requirements. These data and samples are used to create NEON data products, and are documented in the NEON Scientific Data Products Catalog (RD [03]).

Along with the echosounder used to collect bathymetric data, the side-scan and down imaging products are used to define bottom morphology of lake and non-wadeable streams. Since the side-scan images cover an approximate width of 20 meters, the images obtained from the linear transects across the water bodies are collated to produce a map of the bottom morphology using additional software.

1.3 Acknowledgments

The field protocol used by NEON for producing bathymetric and morphometric maps of the lakes and non-wadeable streams follows the general requirements set forth by the U.S. Army Corps of Engineers (2002) and Heyman et al. (2007; RD[01]).

2 RELATED DOCUMENTS AND ACRONYMS

2.1 Applicable Documents

Applicable documents contain higher-level information that is implemented in the current document. Examples include designs, plans, or standards.

AD[01]	NEON.DOC.004300	EHS Safety Policy and Program Manual
AD[02]	NEON.DOC.004316	Operations Field Safety and Security Plan
AD[03]	NEON.DOC.000724	Chemical Hygiene Plan and Biosafety Manual
AD[04]	NEON.DOC.050005	Field Operations Job Instruction Training Plan
AD[05]	NEON.DOC.014051	NEON FSU Field and Laboratory Procedures Quality Assurance Plan

2.2 Reference Documents

Reference documents contain information that supports or complements the current document. Examples include related protocols, datasheets, or general-information references.

RD[01]	NEON.DOC.000008	NEON Acronym List
RD[02]	NEON.DOC.000243	NEON Glossary of Terms
RD[03]	NEON.DOC.002652	NEON Level 1, Level 2, and Level 3 Data Products Catalog
RD[04]	NEON.DOC.001271	TOS Protocol and Procedure: Manual Data Transcription
RD[05]	NEON.DOC.001646	General AQU Field Metadata Sheet
RD[06]	NEON.DOC.001152	NEON Aquatic Sample Strategy Document
RD[07]	NEON.DOC.001154	AOS Protocol and Procedure: Aquatic Decontamination
RD[08]	NEON.DOC.001862	ATBD Lake Bathymetry and Morphology Data Products
RD[09]	NEON.DOC.001085	AOS Protocol and Procedure: Stream Discharge
RD[10]	NEON.DOC.002494	Datasheets for AOS Sample Shipping Inventory
RD[11]	NEON.DOC.003104	Datasheets for Bathymetry and Morphology of Lakes and Non-Wadeable Streams

2.3 External References

ER[01]	Heyman, W.D., J-L. B. Ecochard, and F.B. Biasi. 2007. Low-cost bathymetric mapping for tropical marine conservation – A focus on reef fish spawning aggregation sites. Marine Geology, 30: 37-50
ER[02]	HumminBird Product Manual: Operations Manual. 2012. HumminBird 1198c SI Combo. Johnson Outdoor Marine Electronics. Racine, WI.

2.4 Acronyms

Acronym	Definition
DEM	Digital Elevation Model
DGPS	Differential Global Positioning System
LCD	Liquid Crystal Display
MMC	Multi-Media Card
NAD83	North American Datum of 1983
P&P	Procedure and Protocol
PVC	Polyvinyl Chloride
USGS	U.S. Geological Survey
UTM	Universal Transverse Mercator
WAAS	Wide Area Augmentation System
YSI	Yellow Springs Instrument Co.

2.5 Definitions

Bathymetry: Underwater depth of an aquatic ecosystem.

Morphology: Structure and arrangement of features within the lake watershed and lake bottom. It can include the shape of the surface of a lake and the arrangement of rocks and sediments.

Fathometer: Type of echo sounding system ('sounding' is the measurement of water depth) using active sonar.

Sonar: Technique that uses sound propagation. The active sonar emits pulses of sounds and records echoing returns. When used in water it is more frequently known as hydroacoustic and involves the use of an echo sounder.

Epilimnion: Top layer of water of a stratified lake, denoted by highest temperatures and least dense water in the summer.

Hypolimnion: The dense bottom layer of a stratified lake that sits below the thermocline. This layer is denoted by cooler summer temperatures and slightly warmer winter temperatures relative to the epilimnion.

Thermocline: A distinct layer in a body of water where the change in temperature is more rapid than the increase in depth. The denser and cooler layer below the thermocline is the hypolimnion. The warmer upper layer is termed the epilimnion.

3 METHOD

This protocol describes the steps required to collect data for creation of bathymetric and morphological maps utilizing an acoustic sonar system. Bathymetric and morphological data are collected to produce 2D and 3D bathymetric maps; and to characterize the structure of the waterbody by creating morphological maps of the underwater environment. Bathymetric and morphometric data add another dimension to geographic mapping and modeling and can be used either as a background layer or as a 3D surface for draping thematic maps such as benthic habitats, organism habitats or geologic data.

A vessel is mounted with the DGPS and sounding equipment and driven across the lake or non-wadeable stream surface in a gridded pattern. Data points, including depth and GPS position, and side scan sonar images are recorded every second. The field protocol used by NEON for producing bathymetric and morphometric maps of the lakes and non-wadeable streams follows the general requirements set forth by the U.S. Army Corps of Engineers (2002) and Heyman et al. (2007; ER[01]). While the equipment is not the same, the assumptions remain valid. The U.S. Army Corps approach entails the use of a dual-beam echosounder that is mounted on a large research vessel and capable of mapping large areas. The equipment utilized here also uses an echosounder, but it is a dual beam high frequency system that is better able to accurately (<1 cm) detect bathymetry of shallow systems. It is combined with WAAS GPS technology which increases the horizontal accuracy. The echosounder transmits at a dual frequency of 200/83 kilohertz at beam angles of 6^{o} and 19^{o}, respectively. Water depths are determined by the echo sounder based on the speed of sound in water and compensated for temperature. Recent advances in echo-sounding equipment and the possibility to combine echo-sounding with side-scan sonar, results in acoustic returns that provide information regarding bathymetric (depth), as well as recording the strength of sound energy that bounces back (called "backscatter"). This information is used to identify the composition of the underwater sediments. The side-scan and down-imaging sonar data allow for the identification of water bottom characteristics (biological and physical) otherwise not visible to the naked-eye. This technology facilitates the identification of changes in the morphometry of water bodies over time that may result from high impact events or long term changes in the environment. The shoreline at the time of sampling is mapped with a handheld Trimble GPS unit in continuous mode. These data are imported into GIS and used for interpolation. Data collected in the field are formatted and downloaded into formats required for post-processing and data product creation (RD[08]).

Data will be collected every year (minimum of every 5 years) during the peak of the summer, defined by maximum cumulative growing degree days. In the case of a major flow event (e.g., significant storm, flood, and drought), an additional survey may be conducted to document bathymetric changes when safe conditions allow.

Standard Operating Procedures (SOPs), in Section 7 of this document, provide detailed step-by-step directions, contingency plans, sampling tips, and best practices for implementing this sampling procedure. To properly collect and process samples, field technicians **must** follow the protocol and associated SOPs. Use NEON's problem reporting system to resolve any field issues associated with implementing this protocol.

The value of NEON data hinges on consistent implementation of this protocol across all NEON domains, for the life of the project. It is therefore essential that field personnel carry out this protocol as outlined in this document. In the event that local conditions create uncertainty about carrying out these steps, it is critical that technicians document the problem and enter it in NEON's problem tracking system.

The procedures described in this protocol will be audited according to the Field Audit Plan (AD[07]). Additional quality assurance will be performed on data collected via these procedures according to the NEON Data and Data Product Quality Assurance and Control Plan (AD[08]).

4 SAMPLING SCHEDULE

4.1 Sampling Frequency and Timing

Bathymetry measurements in lakes and non-wadeable streams shall be completed a minimum of every 5 years and a maximum of once per year during NEON Operations unless an extreme event resulting in substantial physical change occurs. The survey frequency will be determined on a site by site basis. The timing of these samples shall follow the procedures outlined in the NEON Aquatic Sample Strategy Document (RD [05]).

Sampling for bathymetry and morphology in lakes and non-wadeable streams shall take place within +/- 2 weeks of peak greenness for first sampling event and +/- 2 weeks of first sampling event timing in subsequent years. Sampling time during the day should remain the same for all sites and all years. Sampling timing will vary for each site based on water body area (size) and seasonal conditions (wind, lightening, etc.). It is advised that surveys are started as early in the day as possible to complete the survey. Surveys that take longer than one day to complete will resume the following day.

4.2 Criteria for Determining Onset and Cessation of Sampling

A baseline lake or non-wadeable stream bathymetric and morphological map is generated during the first year of operations at each site during the period of peak greenness as defined by maximum cumulative growing degree days. The annual timing of such bathymetric surveys shall remain the same for each individual site, so as to have seasonal comparison at sites sampled at the same time of year each year. The sample timing should remain consistent within and across Domains based on peak greenness. The specific dates are determined using multivariate statistics and site specific historical information (see RD[05]).

4.3 Timing for Laboratory Processing and Analysis

Data collected during the bathymetric survey should be downloaded and saved to the appropriate location at the Domain Support Facility. These data can be reviewed using the HumViewer program. This process should not exceed four hours of time.

4.4 Sampling Timing Contingencies

Table 1. Contingent decisions

Delay/ Situation	Action	Outcome for Data Products
Hours	Should the bathymetric mapping be interrupted or stopped at any point during the sampling, the data are flagged. Should the continuation of that sampling take place the following day, technicians shall ensure that the set-up is identical to the previous day and that no major changes in the lake or non-wadeable stream have taken place (+/- 15 cm water height difference).	No adverse outcome.
	Do not undertake bathymetric sampling if wind speeds exceed 5 knots. Either wait for the weather to change and attempt a mapping session later in the day, or postpone to another day.	No adverse outcome.
	If equipment stops functioning during sampling, verify equipment and start sampling again as soon as possible. If you restart sampling the next day and sampling conditions are very different (turbidity of water, weather, etc.), start sampling from the beginning.	No adverse outcome.
	If weather becomes unsafe during sampling, stop and resume or restart as soon as possible. If you restart sampling the next day and sampling conditions are very different (turbidity of water, weather, etc.), start sampling from the beginning.	No adverse outcome.
5 Days or More	Should conditions change while on the water and in the middle of a mapping project, note this in the comments section of the field datasheets and stop working. Save the data, turn off all equipment and start re-surveying as soon as conditions permit. If conditions have changed substantially or more than 5 days have passed, re-start the bathymetric mapping.	No adverse outcome.

4.5 Sampling Specific Concerns

A bar check on the echo sounder is performed at the beginning of each day of data collection by comparing the echo sounder depth reading with that of a weighted measuring tape. Navigate the boat to different areas and record the depths from the echo sounder and the weighted line. Adjust the offset (draft of transducer below the water surface) of the transducer in the on-board software until depth readings and the depth of the weighted line agree to within approximately 5 cm (Linhart and Lund, 2008).

Bathymetric mapping requires calm conditions in order to improve the accuracy and precision of the data acquired. Pitch, roll and heave can affect the angle at which the acoustic beams are delivered in the water column and received by the transducer on the boat. Should the boat be at an angle the apparent depth will differ substantially from the actual depth.

Data are post corrected to account for the average water column speed of sound calculated from the water temperature profiles. Quality assurance and quality control is also performed on the data in the post-processing stage (see RD[08]).

5 SAFETY

This document identifies procedure-specific safety hazards and associated safety requirements. It does not describe general safety practices or site-specific safety practices.

Personnel working at a NEON site must be compliant with safe field work practices as outlined in the Operations Field Safety and Security Plan (AD[02]) and EHS Safety Policy and Program Manual (AD[01]). Additional safety issues associated with this field procedure are outlined below. The Field Operations Manager and the Lead Field Technician have primary authority to stop work activities based on unsafe field conditions; however, all employees have the responsibility and right to stop their work in unsafe conditions.

In addition the following safety guidelines are provided:

1. Due to site-specific hazards that may be encountered technicians may perform GPS positioning around the water body, and measurements for inflow and outflow (where applicable), without dismounting from the vessel. In addition, technicians are required not to put hands and feet in waters where alligators are present and to make sure a safe distance from hazards is maintained.
2. All personnel must be wearing a personal flotation device prior to entering the boat.
3. All employees shall have access to a form of communication with other team members such as a two-way radio.
4. Technicians should be aware of any site-specific hazards and to the waters of that particular location (i.e., navigation hazards etc.)

6 PERSONNEL AND EQUIPMENT

6.1 Equipment

The following equipment is needed to implement the procedures in this document. Equipment lists are organized by task. They do not include standard field and laboratory supplies such as charging stations, first aid kits, drying ovens, ultra-low refrigerators, etc.

Table 2. Equipment list – Field equipment

Item No.	R/S	Description	Purpose	Quantity	Special Handling
Durable items					
	R	Container with latch top	Transporting and storing the HumminBird	1	N
	R	High Accuracy Handheld GPS unit (Trimble)	Mapping the shoreline and verifying HumminBird location values	1	N
MX100453	R	HumminBird 1198c SI Combo Echosounder and side imaging sonar	Creating bathymetric imagery, marking locations, and monitoring speed	1	N
	R	SD Memory cards 8 GB minimum	Storing bathymetric imagery	2	N
	R	Mounting Brackets	Mounting the HumminBird on the boat	1	N
	R	Cross bar mounting pole	Mounting the HumminBird on the boat	1	N
	R	12V portable battery packs	Powering the HumminBird	2	N

Item No.	R/S	Description	Purpose	Quantity	Special Handling
MX103014	R	Flowmeter and top setting wading rod (FH-950)	Measuring inflow and outflow velocity	1	N
	S	Measuring Tape with weight	Calibrating depth	1	N
	R	Camera	Photographing site locations	1	N
	R	Hip Waders (when necessary)/boots/	Safe wading	1	N
	R	Bucket, 5 Gallon	Calibrating the FH-950 flowmeter	1	N
Consumable items					
	R	Rite in the rain notebooks	Taking notes	2	N
	R	Pencils	Recording data	2	N
	R	Multiple copies of data sheets for inflow, outflow, and lake stretch	Recording data	4	N
	R	Bleach	Decontaminating equipment	Ongoing	N

R/S=Required/Suggested

Table 3. Equipment list – General boating equipment

Item No.	R/S	Description	Purpose	Quantity	Special Handling
Durable items					
	R	Boat		1	Y
	R	Anchor with rope		1	N
	R	Oars		2	N
	R	Trolling Electric Motor		1	Y
	R	Battery (12 volt)		up to 3	Y
	R	Safety kit for boat (e.g., flares, bailer, float with rope)		1	Y
	R	First Aid Kit		1	N
	R	Personal Flotation Devices (PFDs)		1 per person	N
MX101642	R	Handheld wind meter	Measuring wind speed before operating boat	1	N
Consumable items					
		(none)			

R/S=Required/Suggested

6.2 Training Requirements

All technicians must complete protocol-specific training for safety and implementation of this protocol as required in Field Operations Job Instruction Training Plan (AD[04]).

All personnel required to operate a boat shall be trained through a program approved by NEON Environmental, Health, and Safety. All others shall be aware of boating safety procedures.

Personnel are to be trained in lake and non-wadeable stream bathymetry and morphometry measurements and safe working practices for lake and non-wadeable stream work.

6.3 Specialized Skills

Where applicable, personnel will be licensed to operate a boat and able to safely handle an electric motor and drive a boat safely.

6.4 Estimated Time

The time required to implement a protocol will vary depending on a number of factors, such as skill level, system diversity, environmental conditions, and distance between sample plots. The timeframe provided below is an estimate based on completion of a task by a skilled two-person team (i.e., not the time it takes at the beginning of the field season). Use this estimate as framework for assessing progress. If a task is taking significantly longer than the estimated time, a problem ticket should be submitted.

We estimate sampling for bathymetry and morphology in lakes requires 2 technicians between 5 to 10 hours each sampling day plus travel to and from the site.

7 STANDARD OPERATING PROCEDURES

SOP A Preparing for Sampling

1. Ensure memory cards are blank. If files are present, confirm data and photos have been uploaded prior to deleting.
2. Verify all equipment is available.
3. Fully charge all batteries and electronic equipment the night before. DO NOT assume that batteries are functional or fully charged even if new.
4. Ensure all equipment is decontaminated with bleach (see NEON Aquatic Decontamination Protocol RD[07]).
5. Print datasheets.
6. For sites with visible flowing inlets and outlets, calibrate Hach FH-950 electromagnetic velocity meter every day that it is used. Check the zero-velocity reading by placing the meter in a bucket of still water and following the directions in the manual that comes with the meter for the zero check and, if necessary, zero adjust.

SOP B Field Sampling

Ensure the General AQU Field Metadata Sheet (RD [10]) is completed.

B.1 Bathymetry (Depth)

1. Ensure the boat plug is inserted.
2. Mount the motor on the boat (if not already mounted).
3. Once the boat and motor are in the water, immediately check the motor is working properly by lowering the motor into the water and turning it on.
4. Load all the equipment onto the boat making sure weight is evenly distributed.
5. Install and fix the mounting rod onto the bow of the boat (this will vary according to the type of boat; Figure 3).
6. Set-up the sounder on the mounting rod.
   a. Make sure the sounder is placed at the front of the boat in order to avoid disturbance from the motor and the effect of the water.
   b. Place the sounder at 0.3 m below the surface of the water. Should this not be possible due to the boat type, record the depth at which the sounder is installed for later data correction. In addition, if you have windier conditions you may want to lower the depth sounder to 0.5 m. **Record the final depth of the sounder on the datasheet.**
7. Setup the transducer on the front of the boat.
   a. The transducers should NOT be placed where there is interference from wave action. (This will depend on the boat type).
   b. Ensure the transducer is positioned horizontally to the lake or stream bottom, facing backwards and with a slight tilt (**Error! Reference source not found.**). Ensure that the transducer cord is not too tight to prevent the cord from breaking free from the transducer.
   c. The transducer should be placed directly under the DGPS antenna in order to reduce errors (Figure 3).
8. Ensure that all connectors between the instruments are securely attached to the HumminBird Unit (Figure 4 and Figure 5). And ensure that there is no stress on the cable where it enters the transponder (may be helpful to zip tie a short loop in the cable)
9. Ensure 2 blank SD cards have been inserted into the card slot (Figure 6):
   a. Remove the SD memory card slot cover.
   b. Position the SD memory card with the label facing the left side of the unit. Press down until the card clicks into place.
   c. Close the slot cover and turn the knob ¼ of a turn to close. DO NOT over-tighten as this will decrease the water resistance and may damage the cover (5).
10. Connect the main HumminBird unit to one of the 12V batteries, by first connecting the ground (black) then the hot (red). (*Ensure that the cover to the battery pack is shut securely in order to*

avoid potential spraying by water). It is recommended by the manufacturer that the battery have at least 10V of power; signal transmission may be affected with low battery power.

11. Turn on the HumminBird GPS unit with the POWER/LIGHT key.
12. Navigate to the location of the staff gage.
13. Take a reading of the lake level and record on datasheet (Figure 7).

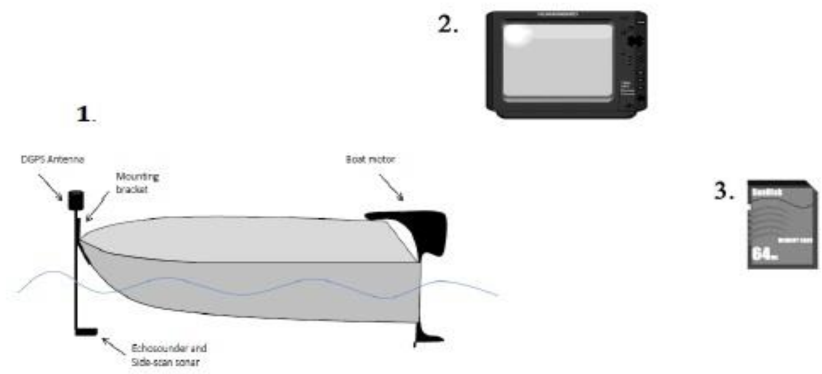


Figure 3. Bathymetric mapping system components. 1) Placement of sounder and transducer on the boat; 2) HumminBird main control panel; and 3) SD memory cards

Figure 4. Transducer set up with service loop to prevent over tensioning the wire coupling

Figure 5. Rear view of the HumminBird control panel with connector details. 1) Video-Out (RS-232), 2) Power, 3) GPS/Communications, 4) Video Out, 5) Ethernet, 6) Temperature/speed, and 7) Transducer

Figure 6. Insertion of SD cards in HumminBird card slot

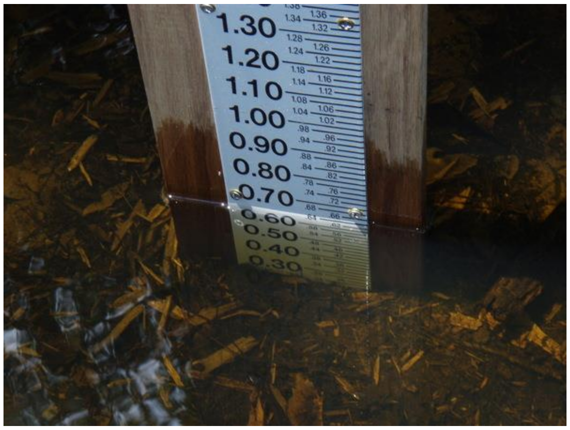


Figure 7. Example of a staff gauge. If conditions are wavy note the mean height.

14. Press MENU to access the **Start-up Options menu** (Figure 8).
15. Verify that you have a good GPS signal and that the sounder is functioning. Upon turning the HumminBird on, the unit will perform a:
    a. **Self-Test**:
        1) Displays results from the internal diagnostic self-test.
            a) From start-up screen select System Status.
    b. **Accessory Test**:
        1) Lists the accessories connected to the unit.
            a) Select view for Accessory Test.
    c. **GPS Diagnostic View**:
        1) Shows a sky chart and numerical data from the GPS receiver with locations of each visible GPS satellite, its number and its signal strength. Verify that the **Fix Type** is set on **Enhanced**, since this is the augmentation (more precise horizontal positioning) using information from WAAS and is required for navigation.
16. Compare the GPS readings (and position accuracy) with the hand held GPS unit. Take readings every minute for 5 minutes from both GPS units and record in the *Bathymetry GPS Unit Cross Validation* datasheet. Use the same handheld GPS receiver for all data collection throughout the day.
17. Verify calibration of echosounder and record this information on the *Bathymetry Settings* datasheet.
    a. Perform a bar check on the echosounder. Navigate to a shallow depth and use the hand held echosounder or a weighted line with depth increments to get a depth reading and record this on the datasheet under Depth Adjustments – Measured Depth. Then, record the depth readings displayed on the HumminBird display unit under Sonar Depth on the datasheet. Navigate to another location that is deeper than the first location. Repeat the measurements and record the results on the datasheet under Depth Adjustments.

b. Make adjustments to offset (draft of transducer below the water surface) of the transducer in the computer software until depth readings and the depth of the aluminum plate agree to within approximately 5 cm and note the final depth on your field datasheet .

c. Adjust the Depth offset in the **Systems Set-up** menu by pressing the menu key twice (can be accessed from any view). Include the transducer depth to the water line (0.3 m; 1 foot) in the total depth when making the adjustment to reflect the true water depth.

18. Record changes made to the echosounder (i.e. sensitivity, SI range, chart speed, color etc.). This information is important for interpreting the data set and for future comparative work in the same aquatic body (A summary of the sonar settings can be found in the **Sonar Menu Advanced**).

a. Use the **View** button to navigate between pages.

b. Only change settings of Sensitivity, SI & DI Sensitivity and SI Enhance – no other setting should be changed:

1) **SI and DI Sensitivity** (all types): controls how much detail is shown on the display and will adjust the sensitivity of all sonar frequencies. Decrease the sensitivity to eliminate clutter particularly if in murky or muddy waters. Do not adjust too low since the unit may not display important sonar returns. Increase the sensitivity in clear waters in order to pick up weaker returns. If too high the screen may become too cluttered. Generally set this lower for hard bottoms and higher for soft bottoms. Sensitivity settings may need to be adjusted multiple times during sampling events if water column and substrate conditions change.

2) **SI Enhance**: adjust your Side Imaging View into 3 categories: Sensitivity, Contrast and Sharpness. Unless needed leave Sensitivity and Contrast at default values and change Sharpness to Medium.

3) **Beam Select**: Ensure the **Beam Select** under the **Sonar** tab is set to 200/83 kHz. **Do not change the beam bandwidth setting.**

4) **Imaging Frequency:** Ensure the **Imaging Frequency** under the **Sonar** tab is set to 455 kHz.

Figure 8. Sonar Menu Tab. Verify and alter these tabs accordingly to the text

19. Using a handheld weather meter, confirm wind speed is lower than 5 knots. If wind speed is higher than 5 knots, suspend sampling. Wind speeds at some aquatic sites may often not go lower than 5 knots (e.g., D09 lakes). At these sites it is recommended to initiate the bathymetry protocol when conditions are perceived to be the most ideal (e.g., early morning).
20. Start recording on the HumminBird unit.
    a. Press the MENU key once in the **Snapshot and Recording View**.
    b. Highlight **Start Recording** and press the RIGHT Cursor key. A waypoint will be created at the boat location and the recording shares the same file name (.SON).
21. Record the waypoint number on datasheet.
22. Note on your lake sketch on the *Lake Boundary GPS* datasheet, your point of departure and note the exact time of departure so that it can be used as a cut-off point for data processing.
23. **Combo views** provide one or more views on the screen. To change the settings for either side of the view, the individual view must be selected as the 'active side'. Ensure that the side-scan imaging sonar view is displayed as one of the views in order to use the information displayed to identify morphological characteristics of the water bottom.
    a. The GREEN ARROW points to the active side (Figure 9):
    b. **Active Side**: Press MENU key once and select ACTIVE SIDE from Menu. Choose RIGHT or LEFT to set the active side.
    c. **Menu**: after you set the Active Side, press MENU key once to access the Menu to provide settings for the active view and the updated display.
    d. **Display Size**: Press MENU key once and select SPLIT POSITION from the Menu. Split Position allows you to adjust the size of the left side of the display. Note: all data are reported in English units.
    e. **Active Cursor**: Press any arrow on the 4 WAY Cursor Control key and the cursor will appear on the active side of the view.

Figure 9. Example of screen with green arrow pointing to the currently “active side’ (referenced by the red circle)

24. Travel at no more than 5 kilometers (3.1 miles or 2.7 knots) per hour. Faster speeds will add errors to the readings by changing the rate of return of the sounder signal versus the GPS coordinate. Monitor your speed on the HumminBird unit.
25. Travel at a constant speed in an approximate grid pattern. Once you start in a direction across the lake or stream as part of a cross section, drive the boat in the same heading (follow this on the screen under the “COURSE’ window. Given the beam angle for the instrumentation, the grids should be spaced approximately 20 meters apart. Stay as close to the shoreline as possible without damaging the instrumentation.

NOTE:

- *While recording press EXIT key to exit the Snapshot and Recording menu and scroll to a different view. Recording will continue*
- *The Slider Bar at the bottom of the Snapshot and Recording view shows the recording progress and remaining space on the SD card*
- *For maximum performance keep the Pings Per Second setting on Auto*

26. Take 10 spot measurements around the shoreline of GPS coordinates with the handheld GPS that has been compared to the boat GPS unit at the beginning of the day. The purpose of providing these spot checks is to test and demonstrate the accuracy of the location information being recorded with the sonar package.
    a. Repeat this same procedure if you encounter an island. Depending on the size of the island – take 6 to 10 GPS readings around the shoreline of the island and record these on the “*In-Lake Boundary GPS Positions*” datasheet (Figure 10). Sketch noteworthy in-lake features on the datasheet.

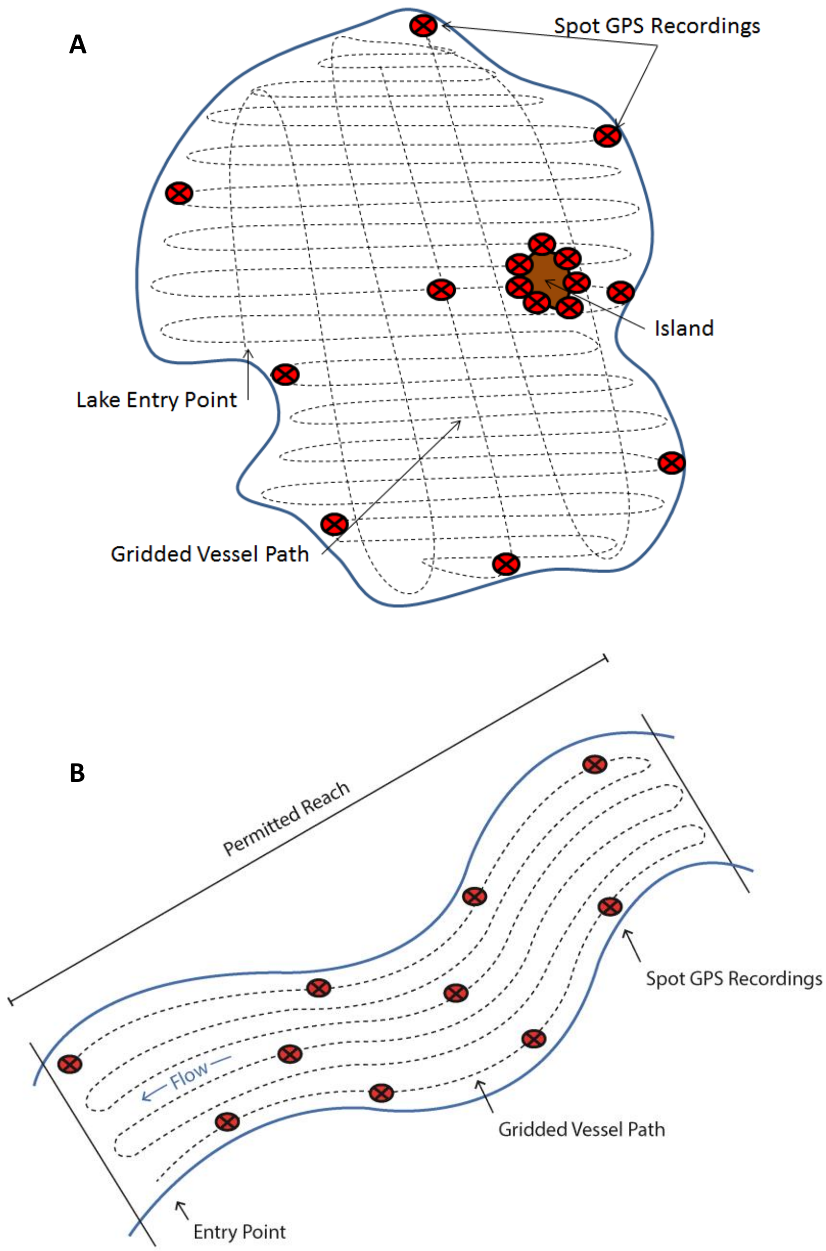


Figure 10. Schematic of gridded pattern undertaken in the vessel and approximate locations for (A) lake shoreline and island point GPS measurements as well as (B) non-wadeable stream GPS measurements. Note: grid lines should be approximately 20 m apart, figures are not to scale.

27. While undertaking the transects, record any main morphologic features seen on the SI images and their GPS positions using the waypoint function (Figure 11). For major morphological features (such as large submerged woody debris, sudden changes in water depth, objects on sediment floor etc.) create a waypoint by pushing the "**Mark**" button on your HumminBird and record the waypoint number and description of your feature on datasheet.

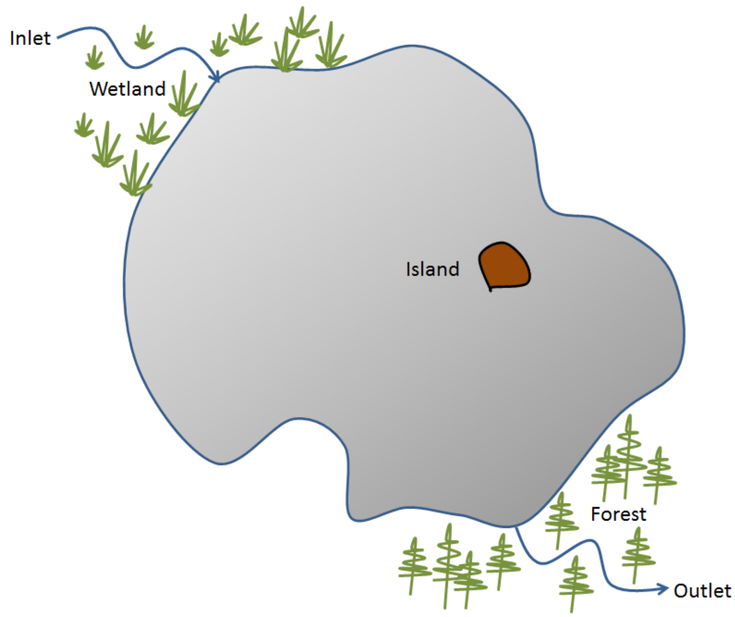


Figure 11. Detailing of morphometric features identified in the field

28. Once the bathymetric mapping is finished, stop recording.
29. To stop recording data, in any view press the **MENU** key once to open the Snapshot **and Recording Menu**.
30. Highlight **Stop Recording** and press the RIGHT Cursor key.
31. Check the lake or stream elevation again by taking a reading from the staff gage, then return to the deepest part of the water body for profiling. Take a reading of the water level and record in your field datasheet.

NOTE: For non-wadeable streams, follow the procedure above with the exception that the bathymetry will cover the full length of the stream section (1 km). Due to the currents in the rivers, it is advisable to run the grid pattern in an upstream-downstream-upstream (Fig 9) manner to avoid potential sideway drifting caused by the currents.

B.2 Inflow and Outflow Morphology and Velocity Measurements

NOTE: This section is only applicable for sites that have clearly identifiable inlets and outlets with surface flows.

1. Return to the incoming river (main one if multiple ones are present) and, if able to dismount from the boat, undertake a flow velocity measurement and cross-sectional area sampling as outlined in Stream Discharge (RD[09]).
2. Repeat this for the outflow.

   a. If you cannot exit the boat, place your boat as close as possible to the inlet and take measurements as accurately as possible.
   b. When dealing with the outflow area, make sure your boat is not parked in-front (upstream) of the measurement area (perpendicular) so that you are not altering the velocity.
3. Navigate to the location of the staff gage.

B.3 Lake Shoreline/Stream Reach

1. Map shoreline with handheld GPS.
2. Select “Data” from the Main Menu.
3. Set File Type to “Rover” and Location to “Default.”
4. Enter a unique file name.
5. If applicable, select the data dictionary previously created.
6. Select “Create” on the upper right side of the page.
7. Enter the antenna height – the height at which the device is collecting data.
8. Select “Line_generic” to create a path around the lake edge.
9. Enter the name of the path in the Comment field. The flashing pencil on the upper right corner indicates the device is recording.
10. Walk around the lake or stream edge or current water line at a normal pace, and hit “OK” to terminate data collection. Note: for larger lakes, it may be more efficient to map the shoreline via boat without the motor and using a pole to maneuver.
11. Repeat steps 1-10 when a distinct higher water level is noted in the field (Figure 12).

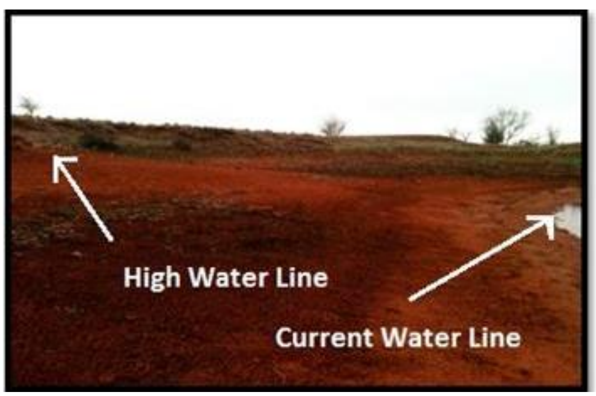


Figure 12. Example of a marked higher water level line. Create a shoreline bathymetry (0 meters depth) line file for each of the current and high water level lines.

B.4 Ending the Sampling Day

1. Equipment Maintenance, Cleaning, and Storage
   a. Ensure all equipment is properly decontaminated and dry prior to storage as per NEON Aquatic Decontamination Protocol (RD[07]) .

1) Refer to the HumminBird 1198c SI Owner's Manual for specific maintenance procedures and equipment troubleshooting (ER[02]).

b. Once per year, the Hach velocity meter must be dynamically calibrated. The calibration facility will be either the FH-950 calibration facility in Loveland, Colorado, or another facility with a calibration flume, under contract with NEON.

SOP C Data Entry and Verification

As a best practice, field data collected on paper datasheets should be digitally transcribed within 7 days of collection or the end of a sampling bout (where applicable). However, given logistical constraints, the maximum timeline for entering data are within 14 days of collection or the end of a sampling bout (where applicable). See RD[04] for complete instructions regarding manual data transcription.

Data file name will follow the format "*domain_site_YYYYMMDD_xx*". For example Lake Suggs in Domain 3 mapped on June 5th, 2011 would read "D3_SUGG_20110605_01". Where xx is an incremental file number, when more than 1 file per day is collected. The lakes and non-wadeable stream sites are coded according to Table 4:

Table 4. Code names for sites

Domain number	Domain name	Site ID	Site name	Site type
3	Southeast	BARC	Barco Lake	Lake
3	Southeast	SUGG	Suggs Lake	Lake
3	Southeast	FLNT	Flint River	Non-Wadeable
5	Great Lakes	CRAM	Lake Crampton	Lake
5	Great Lakes	ROUN	Round Lake	Lake
8	Ozarks Complex	BLWA	Black Warrior River	Non-Wadeable
8	Ozarks Complex	TOMB	Lower Tombigbee River	Non-Wadeable
9	Northern Plains	PRLA	Prairie Lake	Lake
9	Northern Plains	PRPO	Prairie Pothole Lake	Lake
18	Tundra	TOLA	Toolik Lake	Lake

1. Copy all data from the HumminBird unit SD cards into date and location folders on the designated computer.
2. Verify that the following folders are transferred from the SD cards:
   a. SD card 1:
      1) A folder RECORD with a subfolder "R000xx", where xx is the number displayed when you initiate the recording in the field. This should contain one ***.IDX*** and one ***.SON*** file for each recording.
      2) An R000xx.***DAT***; R000xx.***XML***; and an R000xx.***XML.BAK*** file
   b. SD card 2:
   c. Profile***.DOC***
   d. Review the files to ensure that collected data are present and readable.

3. Export data to ***.CSV*** format.
   a. In **HumViewer** open the ***.DAT*** file in the RECORD file (Figure 13)
   b. Select ***File → Export***
   c. Select Position/Depth files ***.CSV*** under Files of Types.
   d. If you are having difficulty converting the files into ***.CSV*** submit a problem ticket.
4. Open the ***.CSV*** file in Excel and enter the following titles (in this order) in the 5 columns:
   a. Lat, Long, Depth (m), Date/Time (UTM), Speed of the boat (m/s), Heading (^{o}) (Table 5).
5. Save the file in ***.CSV*** format (Figure 14).
6. All data and notes shall be transcribed into the database within 7 days.

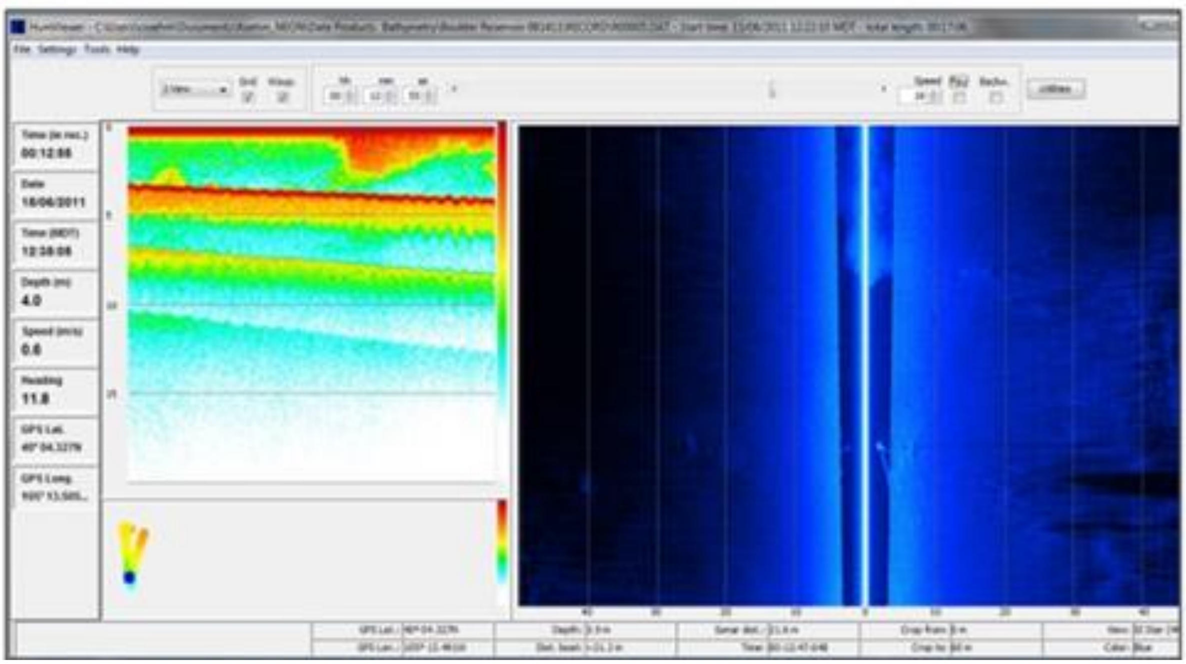


Figure 13. Data file imported into HumViewer.

The far left-hand side of the screen shows the data products including the date and time, depth of water body, speed of the boat, heading of the boat and the Lat. and Long positions. The Upper Left panel is displaying the echo-sounder 200 kHz data including the water column and sediment characteristics. The Lower Left panel is the route taken by the boat. The Right panel shows the 800 kHz Side Imaging display with 15 meters in both directions from the boat.

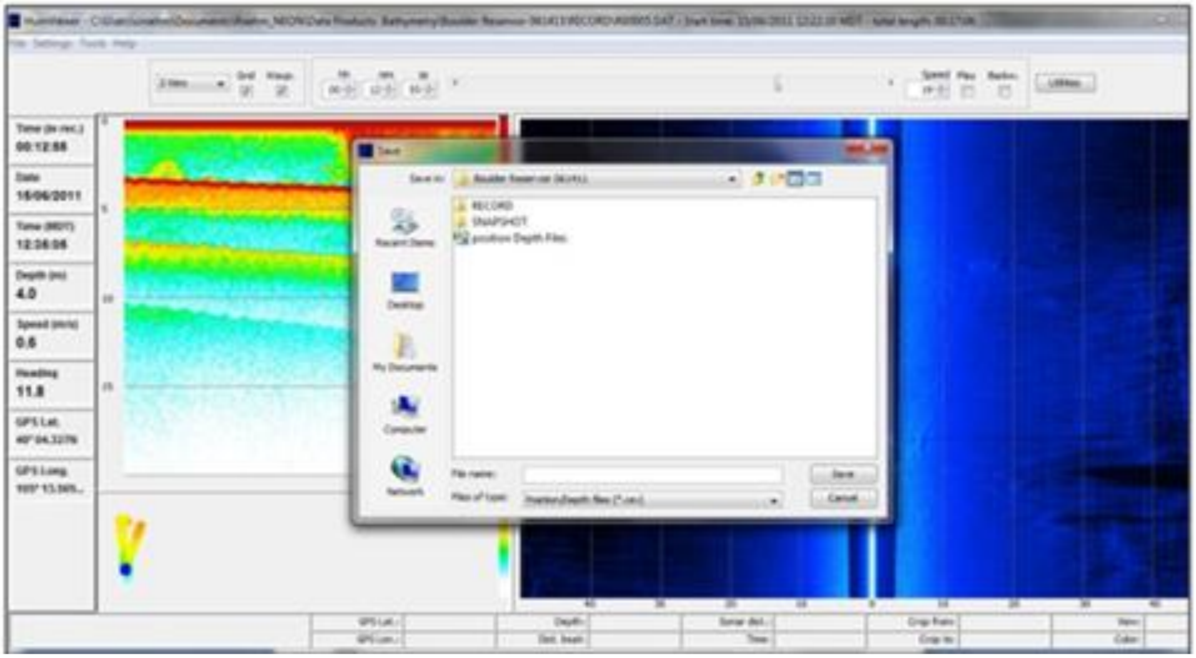


Figure 14. Process for exporting the Lat/Long and Depth data in .CSV format for data pre-processing and eventual import into ArcGIS for the bathymetric map data product

Table 5. Example .csv data format from recording device imported into excel with appropriate column titles added

Latitude	Longitude	Depth (m)	Date/Time (UTM)	Speed (m/s)	Heading (o)
40.07277285	-105.2249965	5.2	15/06/2011 17:52:30	0.1	334.4
40.07277285	-105.2249965	5.2	15/06/2011 17:52:31	0.1	334.4
40.07277285	-105.2249965	5.2	15/06/2011 17:52:32	0.1	334.4
40.07277285	-105.2249965	5.2	15/06/2011 17:52:33	0.1	334.4
40.07277285	-105.2249965	5.2	15/06/2011 17:52:34	0.1	334.4
40.07277285	-105.2249965	5.2	15/06/2011 17:52:35	0.1	334.4
40.07277285	-105.2250055	5.3	15/06/2011 17:52:36	0.1	334.4
40.07277975	-105.2250055	5.1	15/06/2011 17:52:37	0.1	334.4
40.07277975	-105.2250055	5.1	15/06/2011 17:52:38	0.1	334.4
40.07277975	-105.2250055	5.1	15/06/2011 17:52:39	0.1	334.4
40.07277975	-105.2250055	5.2	15/06/2011 17:52:40	0.1	334.4
40.07277975	-105.2250055	5.1	15/06/2011 17:52:41	0.1	334.4

SOP D Sample Shipment

There is no sample shipment for this protocol.

8 REFERENCES

Donohue, I., and J.G. Molinos. 2009. Impacts of increased sediment loads on the ecology of lakes. Biological Reviews, 84(4): 517-531

Dost, R.J.J. and Mannaerts, C.M. (2008) Generation of lake bathymetry using sonar, satellite imagery and GIS. In*:* ESRI 2008: Proceedings of the 2008 ESRI international user conference : GIS, Geography in action*,* August 4-8, 2008, San Diego, Florida / ed. by J. Dangermond. Redmond : ESRI, 2008. 5 p

Heyman, W.D., J-L. B. Ecochard, and F.B. Biasi. 2007. Low-cost bathymetric mapping for tropical marine conservation – A focus on reef fish spawning aggregation sites. Marine Geology, 30: 37-50

Hofmann, H., A. Lorke, and F. Peeters. 2008. Temporal scales of water-level fluctuations in lakes and their ecological implications. Hydrobiologia, 613(1): 85-96.

Linhart, S.M., and K.D. Lund. 2008, Bathymetric contour maps for lakes surveyed in Iowa in 2006*:* U.S. Geological Survey Scientific Investigations Map 3051, 2 sheets.

U.S. Army Corps of Engineers. 2002. Engineering and Design-Hydrographic Surveying Manual No. 1110-2-1003: Washington, D.C., 510 p.

APPENDIX A DATASHEETS

The following datasheets are associated with this protocol:

Table 6. Datasheets associated with this protocol

NEON Doc. #	Title
NEON.DOC.003104	Datasheets for Bathymetry and Morphology of Lakes and Non-Wadeable Streams
NEON.DOC.001646	NEON General AQU Field Metadata Sheet
NEON.DOC.002494	Datasheets for AOS Sample Shipping Inventory

These datasheets can be found in the NEON Document Warehouse.

APPENDIX B QUICK REFERENCES

Step 1 – Check the bathymetry field sampling kit to make sure all supplies are packed.

Step 2 – Set-up and secure the sounder on the mounting rod.

Step 3 – Take a reading of the water level and record on datasheet.

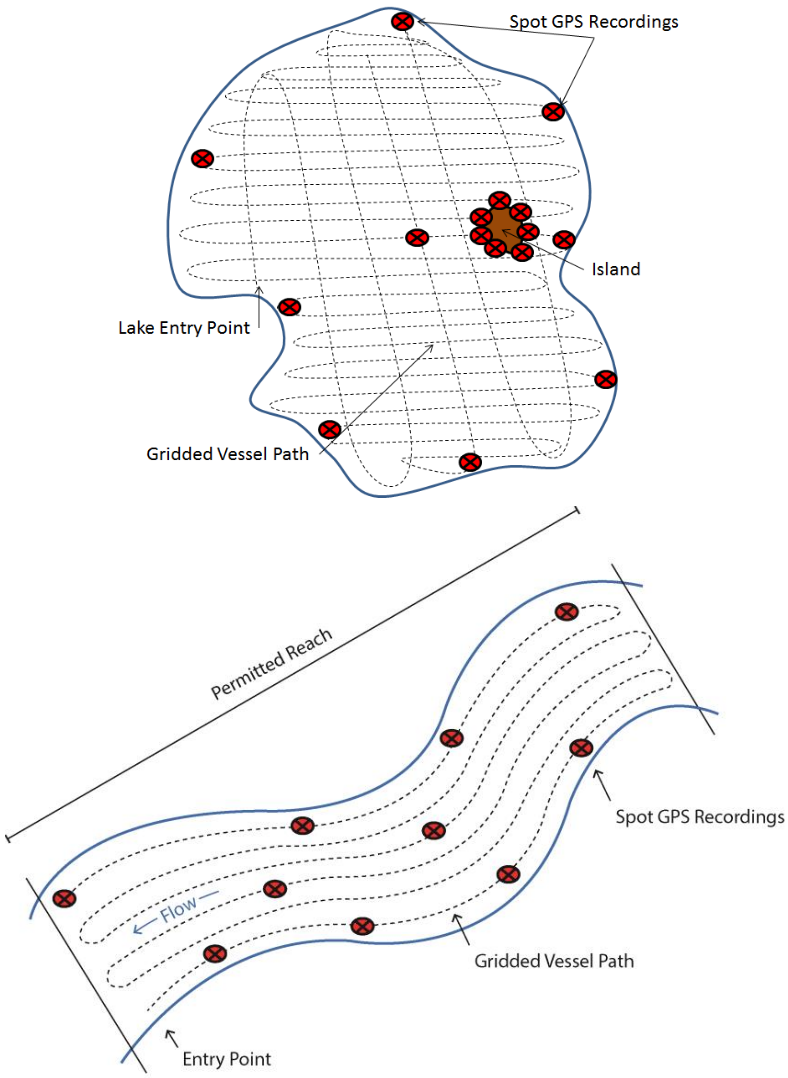
Step 4 – Verify that you have a good GPS signal and that the sounder is functioning.

Step 5 – Compare the GPS readings (and position accuracy) with the hand held GPS unit.

Step 6 – Verify calibration of echosounder.

Step 7 – Record changes made to the echosounder (i.e. sensitivity, SI range, chart speed, color etc.).

Step 8 – Start recording on the HumminBird unit and create a gridded pattern around the lake or non-wadeable stream.



Step 9 – Take 10 spot measurements around the lake or along the stream reach of GPS coordinates with the handheld GPS and collect and record GPS coordinate of the deepest part of the water body

Step 10 – Record all morphological features encountered both within the lake or stream (i.e., islands, lake bottom biological and physical features) and on the shoreline (vegetation type and density, river inlets and outlets, etc.)

Step 11 – Once the transects are completed, stop recording on the HumminBird unit.

Step 12 – For sites with continuously flowing inlets and outlet, undertake a flow velocity measurement and cross-sectional area sampling as outlined in Stream Discharge (RD[09]).

Step 13 – Map shoreline with handheld GPS.

APPENDIX C REMINDERS

Before heading into the field: Make sure you…

- ☑ Collect and prepare all equipment.
- ☑ Fully charge all batteries and electronic equipment the night before.
- ☑ DO NOT assume that batteries are functional or fully charged even if new.

Bathymetric mapping: Be sure to…

- ☑ Travel at no more than 5 kilometers (3.1 miles) per hour. Faster speeds will add errors to the readings by changing the rate of return of the sounder signal versus the GPS coordinate.
- ☑ Record the final depth of the sounder on the datasheet.
- ☑ Travel at a constant speed in an approximate grid pattern.
- ☑ Given the beam angle for the instrumentation, the grids should be spaced approximately 20 meters apart.
- ☑ Stop and clear vegetation from transducer/rod after passing through aquatic vegetation
- ☑ **Do not change the beam bandwidth setting.**
- ☑ Monitor your speed on the HumminBird unit.
- ☑ For maximum performance keep the Pings Per Second setting on Auto.
- ☑ Use the same handheld GPS receiver for all data collection throughout the day.
- ☑ During the bathymetric mapping collect and record GPS coordinate of the deepest part of the lake.
- ☑ If wind speed is higher than 5 knots, suspend sampling.

APPENDIX D ESTIMATED DATES FOR ONSET AND CESSATION OF SAMPLING

See the Site Specific Sampling Strategy Document.

APPENDIX E SITE-SPECIFIC INFORMATION

See the Site Specific Sampling Strategy Document.