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

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See configuration management system for approval history.

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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

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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 a lake. Lake (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 Mannearts, 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 differential 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 lake 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 lake along its longest axis, then subsequent continuous transects are conducted perpendicular to this axis (Figure 1). The instrumentation collects centimeter-scale accurate coordinate positions and depths simultaneously. The combined unit provides a high resolution and high 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 lake outline shapefile to produce 2D and 3D bathymetric maps. Lake bottom morphometric characteristics, such as vegetation extent, sediment characteristics, and sediment compaction, are defined by converting the side-scan images into a master image. Information about volume, surface area and stage curves are then calculated. The maps are used to calculate mean and maximum lake depths along with shoreline and sediment morphometry. Lake surface morphometric characteristics (shape and shoreline development index) are 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.

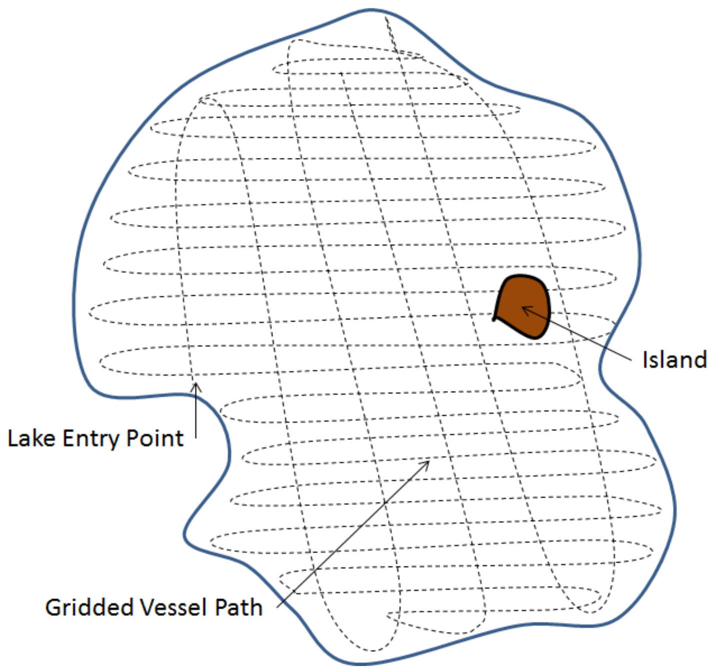

Figure 1. Grid pattern used for determining the lake bathymetry and morphology

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 the software HummViewer.

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).

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	Domain Chemical Hygiene Plan and Biosafety Manual
AD[04]	NEON.DOC.001155	NEON Training Plan
AD[05]	NEON.DOC.050005	Field Operations Job Instruction Training Plan
AD[06]	NEON.DOC.014051	Field Audit Plan
AD[07]	NEON.DOC.000824	Data and Data Product Quality Assurance and Control 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.005003	NEON Scientific Data Products Catalog
RD[04]	NEON.DOC.001271	NEON Protocol and Procedure: Manual Data Transcription
RD[05]	NEON.DOC.001646	NEON 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

2.3 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.

2.4 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 listens for echoes. When used in water it is more frequently known as Hydroacoustics 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 termed the hypolimnion. The warmer upper layer is termed the epilimnion.

3 METHOD

This protocol describes the steps required to collect data for the creation of bathymetric and morphological maps utilizing an acoustic sonar system. Bathymetric and morphological data are being collected in order to produce 2 and 3D bathymetric maps; and to characterize the structure of the systems through 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 *Differential Global Positioning System* (*DGPS*) and sounding equipment and driven across the lake surface in a gridded pattern (Figure 1). 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). While the equipment is not the same, the assumptions remain valid. The USGS 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 proposed in this protocol also uses an echosounder, but rather it is a dual beam high frequency system that is more 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 and 19^{o}, respectively. Water depths are determined by the echo sounder based on the speed of sound in water 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 lake sediments. The side-scan and down-imaging sonar data, allow for the identification of lake bottom characteristics (biological and physical) otherwise not visible to the naked-eye. This technology facilitates the identification of changes in the morphometry of lakes over time that may result from high impact events or long term changes in the environment. The lake outline at the time of sampling is measured with a handheld Trimble GPS unit in continuous mode. The data are imported into GIS and used for interpolation. The data collected in the field is formatted and downloaded into formats required for post-processing and data product creation (see *RD[08]*).

Data will be collected at least every year during the peak of the summer, defined by maximum cumulative growing degree days, or after a major event.

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 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. Given that sampling will take between 3 to 7 hours per lake, the lakes should all be sampled between 9 am and 4 pm.

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 across Domains and within Domains. The specific times are determined using multivariate statistics and site specific historical information (see RD[05]).

4.3 Timing for Laboratory Processing and Analysis

There is no domain lab processing for this protocol.

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 is 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 in lakes 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 whilst on the lake 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 following U.S. Army Corps of Engineers (2002) protocols in order to verify correct calibration of the echosounder. This procedure involves suspending a flat aluminum plate directly below the echosounder at 1 meter for initial calibration. The plate is then lowered in 0.5 m increments, depending on the range of depths expected to be encountered, and then adjusting the offset (draft of transducer below the lake surface) of the transducer in the on-board software until depth readings and the depth of the aluminum plate 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 is post corrected to account for the average water column speed of sound calculated from the temperature profiles made within the lake. 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 lake, 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. current status, tidal charts, 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	Mapping the lake shoreline and verifying Humminbird location values	1	N
MX100453	R	Humminbird 1198c SI Combo	Creating bathymetric imagery, marking locations, and monitoring speed	1	N
MX100453	R	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

Item No.	R/S	Description	Purpose	Quantity	Special Handling
	R	Aluminum plate with rope marked with 50 cm depth increments	Verifying calibration of Humminbird	1	N
	R	12V portable battery packs	Powering the Humminbird	2	N
	R	Lanyards	To secure pencils in the field	2	N
MX103014	R	Flowmeter and top setting wading rod (FH-950)	Measuring inflow and outflow velocity	1	N
	S	Measuring Tape		1	N
	R	Camera	Photographing site locations	1	N
	R	Hip Waders (when necessary)/boots/pp	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 and 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)		1	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
Consumable items					
		(none)			

R/S=Required/Suggested

6.2 Training Requirements

All technicians must complete required safety training as defined in the NEON Training Plan (AD[04]). Additionally, technicians must complete protocol-specific training for safety and implementation of this protocol as required in Field Operations Job Instruction Training Plan (AD[05]).

All personnel required to operate a boat shall be trained through an approved program. 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 3 to 7 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 and functioning properly including fully charged batteries.
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 2).
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 in Appendix G.**
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 bottom, facing backwards and with a slight tilt (Figure 3).
   c. The transducer should be placed directly under the DGPS antenna in order to reduce errors (Figure 2).
8. Ensure that all connectors between the instruments are securely attached to the HumminBird Unit.
9. Ensure 2 blank SD cards have been inserted into the card slot:
   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 (Figure 4).
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*).
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 5)

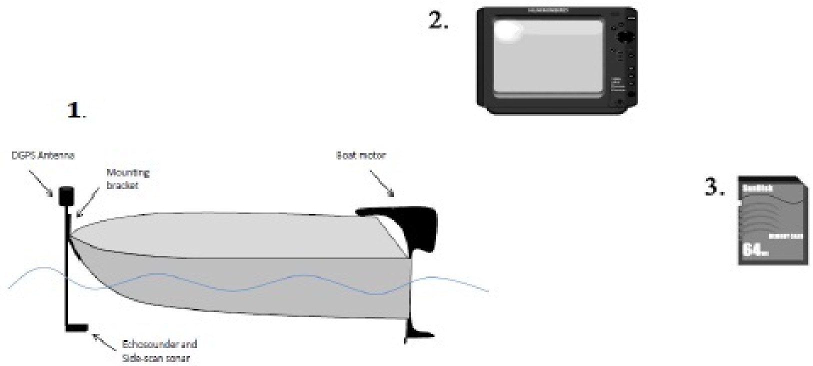

Figure 2. Bathymetric mapping system components. 1) Placement of sounder and transducer on the boat; 2) HumminBird main control panel; and 3) SD memory cards

Figure 3. Set-up and parts for the sonar head

Figure 4. Insertion of SD cards in HumminBird card slot

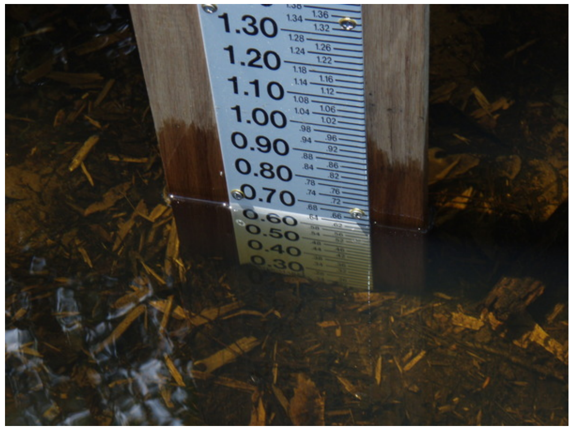

Figure 5. Example of a staff gauge. If conditions are wavy note the mean height.

14. Press MENU to access the **Start-up Options menu.**
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
    b. **Accessory Test**:
        1) Lists the accessories connected to the unit
    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. To exit any menu press EXIT.
17. 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 datasheet (see Appendix F). Use the same handheld GPS receiver for all data collection throughout the day.
18. Verify calibration of echosounder.
    a. Perform a bar check on the echosounder. Suspend the calibration plate (aluminum plate attached to the depth marked rope) at 1 m below the echosounder. Record the depth readings displayed on the GPS unit. Enter this in your bathymetry calibration sheet provided in Appendix G on the GPS unit. Lower the plate at 0.5 m increments and read and record the depth units displayed at each increment up to a maximum depth of 2 meters.
    b. Make adjustments to the offset (draft of transducer below the lake 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 sheet (Appendix G).
    c. Adjust the Depth offset in the **Systems Set-up** menu under **Charts**.

19. 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 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.
        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 6. Sonar Menu Tab. Verify and alter these tabs accordingly to the text

20. Confirm wind speed is lower than 5 knots. If wind speed is higher than 5 knots, suspend sampling.
21. 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).

22. Record the waypoint number on datasheet.
23. Note on your lake sketch, 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.
24. **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 lake bottom.
    a. The GREEN ARROW points to the active side (Figure 7):
    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.
    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 7. Example of screen with green arrow pointing to the currently "active side' (referenced by the red circle)

25. Travel at no more than 5 kilometers 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.
26. Travel at a constant speed in an approximate grid pattern. Once you start in a direction across the lake 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 (Figure 8).

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*

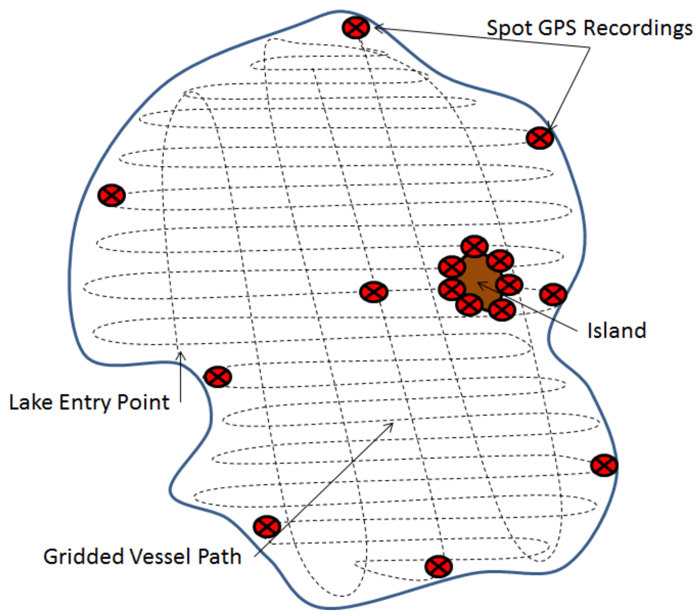

Figure 8. Schematic of gridded pattern undertaken in the vessel and approximate locations for shoreline and island point GPS measurements

27. Take 10 spot measurements around the lake of GPS coordinates with the handheld GPS that has been compared to the boat GPS unit at the beginning of the day (Figure 8) Appendix I.
    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*" sheet in Appendix I (Figure 8).
28. Whilst undertaking the transects, record all morphological features encountered both within the lake (i.e. islands, lake bottom biological and physical features) and on the shoreline (vegetation type and density, river inlets and outlets, etc.) (Figure 9). This data is used for QA/QC of raw image files. Record any main morphologic features seen on the SI images and their GPS positions using the waypoint function. 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 (Appendix G).

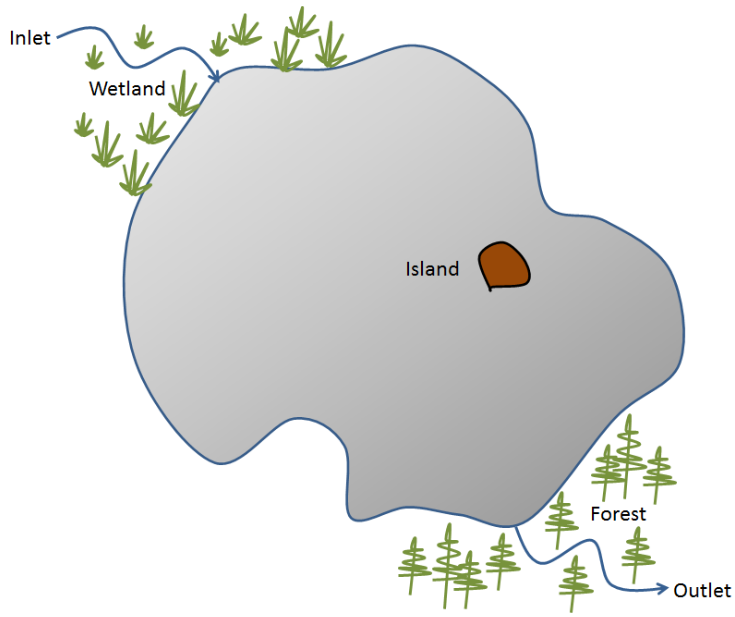

Figure 9. Detailing of morphometric features identified in the field

29. During the bathymetric mapping collect and record GPS coordinate of the deepest part of the lake. Record depth on both the map and on the field datasheet and create a waypoint.
30. Once the bathymetric mapping is finished, stop recording.
31. To stop recording data, in any view press the **MENU** key once to open the Snapshot **and Recording Menu**.
32. Highlight **Stop Recording** and press the RIGHT Cursor key.
33. Check the lake elevation again by taking a reading from the staff gage, then return to the deepest part of the lake for profiling. Take a reading of the lake level and record in your field book (Appendix G).

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 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 continuously flowing inlets and outlets.

1. Return to the incoming river (main one if multiple ones are present) and, if able to dismount form 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. Should you not have permission to exit the boat place your boat as close as possible to the inlet and undertake 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

1. Map lakeshore 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 edge at a normal pace, and hit "OK" to terminate data collection.
11. Repeat steps 1-10 when a distinct higher water level is noted in the field (Figure 10).

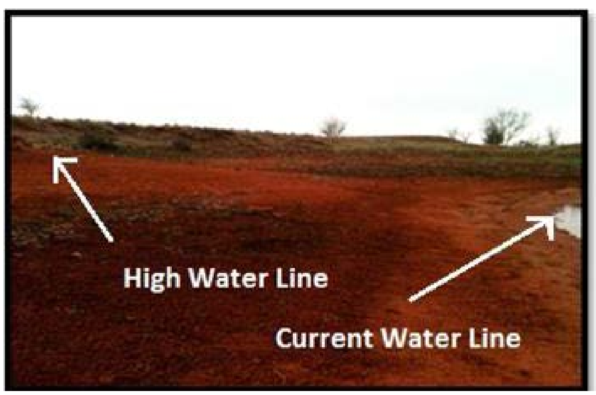

Figure 10. Example of a marked higher water level line. Create a shoreline bathymetry (0 meters depth) line file for each of the current and high water level lines.

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]] .
   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 is 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. Codes 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
5	Great Lakes	CRAM	Lake Crampton	Lake
9	Northern Plains	PRLA	Prairie Lake	Lake
9	Northern Plains	PRPO	Prairie Pothole Lake	Lake
11	Southern Plains	POND	South Pond	Lake
18	Tundra	TOLA	Toolik Lake	Lake
3	Southeast	ICHA	Ichawaynochaway Creek	Non-Wadeable
8	Ozarks Complex	BLWA	Black Warrior River	Non-Wadeable
8	Ozarks Complex	TOMB	Lower Tombigbee River	Non-Wadeable

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***
3. Export data to ***.CSV*** format.
   a. In **HummViewer** open the ***.DAT*** file in the RECORD file (Figure 11).
   b. Select ***File → Export***
   c. Select Position/Depth files ***.CSV*** under Files of Types.
4. Open the ***.CSV*** file in Excel and enter the following titles (in this order) in the 5 columns:

   a. Lat, Long, Depth (m), Depth (m), Date/Time (UTM), Speed of the boat (m/s), Heading (°) (Table 5).

5. Save the file in ***.CSV*** format (Figure 12).

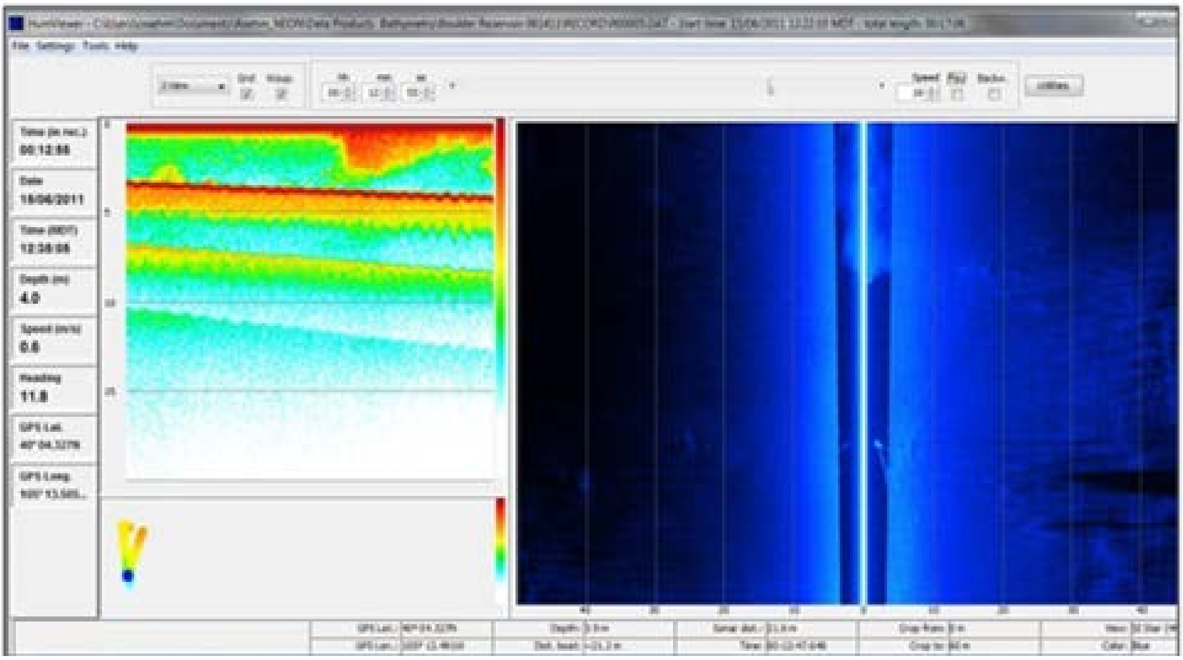

Figure 11. Data file imported into HummViewer.

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.

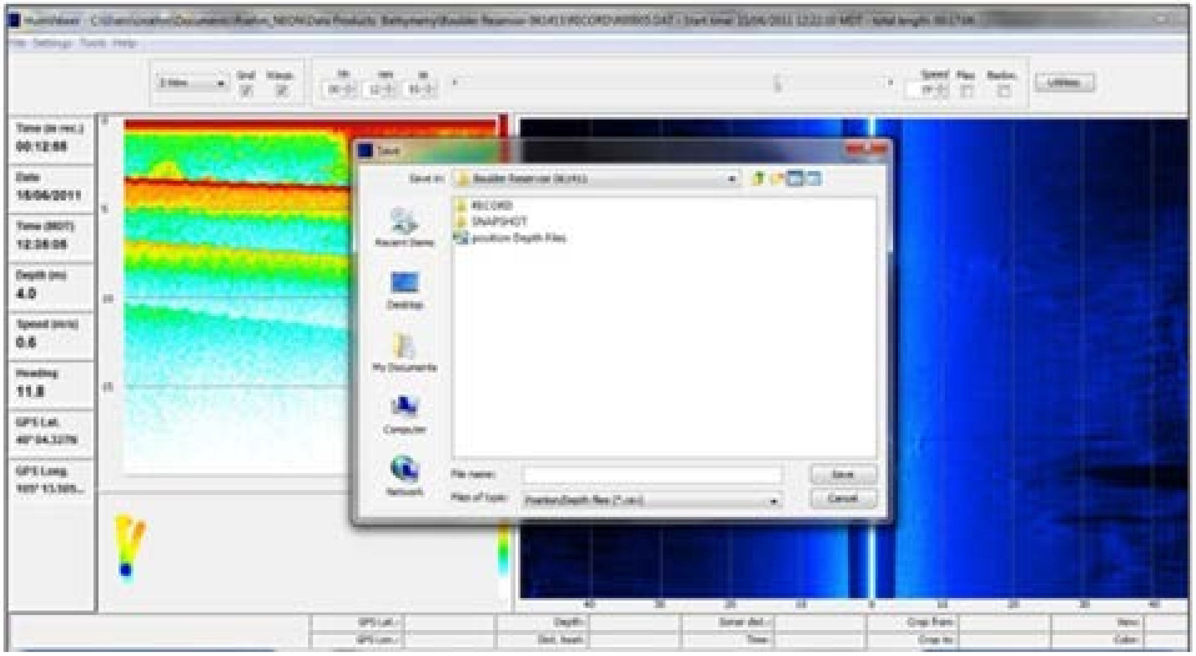

Figure 12. Process for exporting the Lat/Long and Depth data in .CSV format for data pre-processing and eventual import into ArcGIS for the bathymetric map data product

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

6. All data and notes shall be transcribed into the database within 7 days.

SOP D Sample Shipment

There is no sample shipment for this protocol.

8 REFERENCES

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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

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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.

Moses, C.S., A. Nayegandhi, R. Beavers, and J. Brock, 2010. A Service wide Benthic Mapping Program for National Parks: U.S. Geological Survey Open-File Report *2010-1264*, 82 p.

Snyder, J.P. 1987. Map Projections – A working Manual. US. Geological Survey Professional Paper 1395, 383p

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.001646	NEON General AQU Field Metadata Sheet
NEON.DOC.002494	Datasheets for AOS Sample Shipping Inventory

These datasheets can be found in Agile or 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 the sounder on the mounting rod.

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

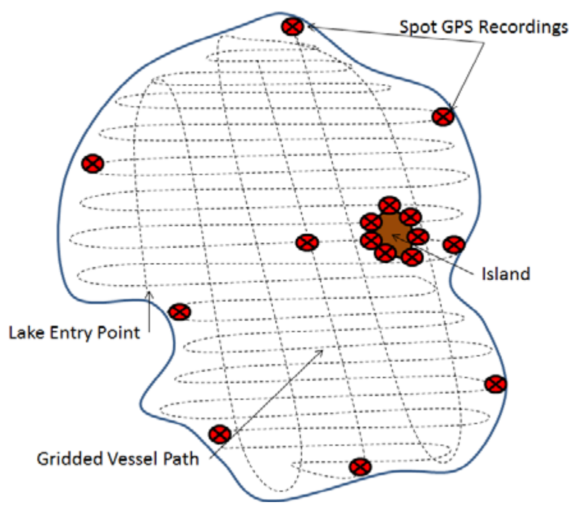
Step 4 – Verify that you have a good GPS signal and that the sounder is functioning.

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.



Step 9 – Take 10 spot measurements around the lake of GPS coordinates with the handheld GPS and collect and record GPS coordinate of the deepest part of the lake

Step 10 – Record all morphological features encountered both within the lake (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 lakeshore 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 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 in Appendix G.
- ☑ 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.
- ☑ **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 on AQU's NEON intranet site.

APPENDIX E SITE-SPECIFIC INFORMATION

See the Site Specific Sampling Strategy Document on AQU's NEON intranet site.

APPENDIX F GPS UNIT CROSS-VALIDATION DATASHEET

The following field data sheets serve as a backup procedure for times when electronic data collection devices (PDA) are not available.

NEON Bathymetry GPS Unit Cross Validation

Domain: ____________ *Time:* ____________ *Staff ID:* ____________

Site: ____________ *Date:* ____________ *GPS Lat:* ____________

Weather: ____________ *Temperature:* ____________ *GPS Long:* ____________

GPS Unit: ____________________________

Latitude	Longitude	Accuracy	Time

APPENDIX G BATHYMETRIC MAPPING SETTINGS

NEON Bathymetry Settings

Domain:	________	*Time:*	________	*Staff ID:*	________
Site:	________	*Date:*	________	*GPS Lat:*	________
Weather:	________	*Temperature:*	________	*GPS Long:*	________

Staff Gauge Height (m)	Start:	Finish:

Depth Adjustments

Depth (m)	**GPS Reading**	**Adjustment**	**Final Depth (cm)**
1			
1.5			
2			

Recording Number	**Start**	**Stop**

Waypoint	Description

	Settings
Sensitivity	
SI Enhance	
Sensitivity	
Contrast	
Sharpness	
SI Range	
Chart Speed	
Down Imaging Beam	*Narrow*

APPENDIX H LAKE BOUNDARY GPS POSITIONS DATASHEET

The following field data sheets serve as a backup procedure for times when electronic data collection devices (PDA) are not available.

NEON Bathymetry Lake Boundary GPS

Domain:		*Time:*		*Staff ID:*	
Site:		*Date:*		*GPS Lat:*	
Weather:		*Temperature:*		*GPS Long:*	

Latitude	Longitude	Accuracy	Time

Sketch:

APPENDIX I IN-LAKE BOUNDARY GPS POSTITIONS DATASHEET

The following field data sheets serve as a backup procedure for times when electronic data collection devices (PDA) are not available.

NEON Bathymetry In-Lake Boundary GPS

Domain: ____________ *Time:* ____________ *Staff ID:* ____________

Site: ____________ *Date:* ____________ *GPS Lat:* ____________

Weather: ____________ *Temperature:* ____________ *GPS Long:* ____________

Latitude	Longitude	Accuracy	Time

Sketch: