STANDARD OPERATING PROCEDURE (SOP): POST-PROCESSING OF BATHYMETRIC AND SIDE SCAN SONAR DATA FROM NEON LAKES AND NON-WADEABLE STREAMS

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A	01/03/2020	ECO-06325	Initial release

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LIST OF TABLES AND FIGURES

1   DESCRIPTION

Contained in this document are details concerning the standard operating procedure (SOP) for collecting, processing, and producing Level 4 bathymetric and habitat maps at NEON aquatic lake and non-wadeable river sites. Specifically, the processes necessary to convert "raw" electronic survey data and field measurements into Level 4 spatial data products and their associated uncertainties are described. These data are collected using a boat-mounted system applied during manned surveys of NEON lakes and river sites. A Humminbird 1198c SI Combo, dual beam echo sounder with side scan sonar and WAAS GPS are used to collect bathymetric (depth) and backscatter (signal strength) data. Depth data are converted into depth contour lines for the development of a bathymetric map (Figure 1a). The side scan sonar data are used to create a mosaic of bottom imagery (Figure 1b) from which habitat classes are assigned and a habitat map is generated (Figure 1c). Bathymetric surveys are completed every 5 years; if an extreme event results in substantial changes to the physical environment then an out-of-cycle survey maybe requested.
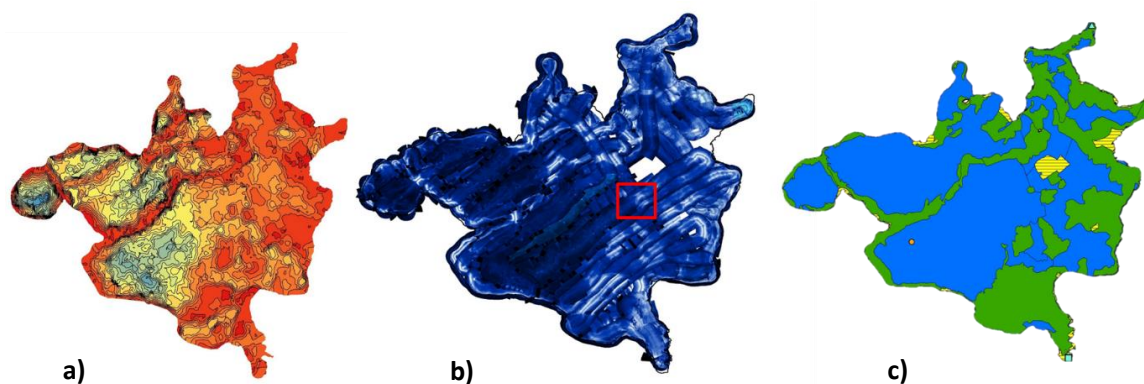

Figure 1. Example bathymetric map (a), side scan sonar mosaic of bottom imagery (b), and a classified habitat map (c).

1.1   Purpose

This document details how to create NEON Level 4 data products for bathymetric and habitat maps from Level 0 data, and how to organize ancillary data obtained via instrumental measurements using steps outlined in the AOS Protocol and Procedure: Bathymetry and Morphology of Lakes and Non-Wadeable Streams (RD[04]). It includes a description of the field data collection procedures, appropriate background information, an itemized list of data products, quality assurance and control methods used, and approximations and/or assumptions made for the collection of data used to create the bathymetric and habitat maps.

1.2   Scope

This document describes how to derive Level 4 data from Level 0 data for the AOS Protocol and Procedure: Bathymetry and Morphology of Lakes and Non-Wadeable Streams (RD[04]). It does not provide computational implementation details, except for cases where these stem directly from SOP choices and assumptions explained here.

2   RELATED DOCUMENTS, ACRONYMS AND VARIABLE NOMENCLATURE

2.1   Applicable Documents

AD[01]	NEON.DOC.000001	NEON OBSERVATORY DESIGN
AD[02]	NEON.DOC.005003	NEON Scientific Data Products Catalog
AD[03]	NEON.DOC.002652	NEON Level 1, Level 2 and Level 3 Data Products Catalog
AD[04]	NEON.DOC.005005	NEON Level 0 Data Products Catalog
AD[05]	NEON.DOC.004104	NEON Science Performance QA/QC Plan
AD[06]	NEON.DOC.005001	NEON Coordinate Systems Specification

[1] Note that CI obtains calibration and sensor values directly from an XML file maintained and updated by CVAL in real time. This report is updated approximately quarterly, so there may be a lag time between the XML and report updates.

2.2   Reference Documents

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.001197	AOS Protocol and Procedure: Bathymetry and Morphology of Lakes and Non-Wadeable Streams
RD[05]	NEON.DOC.003104	Datasheets for Bathymetry and Morphology of Lakes and Non-Wadeable Streams
RD[06]	NEON.DOC.004857	NEON Standard Operating Procedure: Post-processing of Wadeable Stream Morphology Data from NEON Wadeable Streams
RD[07]	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	Explanation
DGPS	Differential Global Positioning System
DP	Data Product
EBK	Empirical Bayesian Kriging
L4	Level 4
GCS	Geographic Coordinate System
GIS	Geographic Information System
GPS	Global Positioning System
MODIS	Moderate Resolution Imaging Spectroradiometer
NDVI	Normalized Difference Vegetation Index
PCS	Projected Coordinate System
SOP	Standard Operating Procedure
UTM	Universal Transverse Mercator
WAAS	Wide Area Augmentation System
WGS	World Geodetic System

2.5 Spatial File Types and Extensions

2.5.1 Shapefile

Extension	Explanation
.shp	The main file that stores the geometry of a feature as a series of vertices (e.g. point, line, polygon)
.shx	The index file that stores the position of the feature geometry
.dbf	The dBASE table file stores the attribute information of the features and maintains a one-to-one relationship between geometry and attributes based on record number
.prj	The projections definition file stores geographic coordinate and projection system information
.xml	Extensible Markup Language file contains metadata associated with the file and can be viewed in a text editor
.sbn	Spatial index file for optimizing spatial queries (when used in conjunction with .sbx)
.sbx	Spatial index file for optimizing loading time of spatial queries (when used in conjunction with .sbn)
.cpg	Encoded plain text file describes shapefile text character set

2.5.2 Image File

Extension	Explanation

.tif	Tagged Image File format stores an array of pixels to form a high-quality raster graphic
.tfw	World File for TIF contains the location, scale, and rotation of the data that is stored as a .tif image for geographic reference

2.5.3   Earth Viewer File

Extension	Explanation
.kml(z)	Keyhole Markup Language file is an xml format extension for visualizing geographic data in an internet-based geobrowser like Google Earth

2.5.4   Sonar File

Extension	Explanation
.DAT	Binary data file which contains information about the sonar time, positions and settings
.SON	8-bit file which contain the sonar data echograms
.IDX	Index file of successive pings corresponding to .SON file

3   DATA PRODUCT DESCRIPTION

3.1   Variables Reported

The Bathymetry and Morphology of Lakes and Non-Wadeable Streams (RD[04]) and related L4 DPs provided by the procedures documented in this SOP are displayed in the accompanying file NEON Data Variables for Bathymetric and Morphological Maps (NEON.DP4.00132). A summary of the L4 DPs associated with this SOP are detailed in the following table.

Table 1. Metadata for L4 Data Products Associated with the Bathymetric (BATH) and Habitat (HAB) Map with Estimated File Sizes and Descriptions

File Type	File Size Range	Description
BATH_contour.shp	70 kb – 300 kb	Shapefile format containing vector data of contour depth lines at a specific interval.
BATH_shorePolygon.shp	100 kb	Shapefile format containing vector data of the closed polygon boundary around the shoreline.

File Type	File Size Range	Description
BATH_tracks.csv	500 – 1,000 mb	Table containing longitude, latitude, and depth of survey track and meters above sea level based on gauge height (height of water surface) reading(s) collected during survey.
BATH_volume.csv	< 1,000 kb	Table containing water volume calculation, 2D area (flat surface), and 3D area (sum of surface area) calculations at successive depths.
BATH GE.kmz	300 kb – 2,700 kb	Earth Viewer file of derived bathymetric map viewable in Google Earth.
BATH_Map.pdf	400 kb – 1,300 kb	Portable document format for viewing derived bathymetric map.
BATH.tif	1,000-1,700 kb	Image file of interpolated depths.
HABITAT.shp	40 - 300 kb	Shapefile format of classified habitat features derived as polygons.
HABITAT_area.csv	< 500 kb	Table containing unique fields for each habitat classification, total area of each classification, and percent cover of classification.
HABITAT_GE.kmz	150 - 170 kb	Earth Viewer file of derived habitat map viewable in Google Earth.
HABITAT_Map.pdf	156 – 350 kb	Portable document format for viewing derived habitat map.

3.2   Input Dependencies

Input dependencies provided in Table 2.

Table 2. List of the equipment used to collect L0 DPs that are transformed into L4 DPs in this SOP.

Description	Sample Frequency	Units	Data Product Number
Humminbird 1198c SI Combo Echo sounder and side imaging sonar with DGPS antenna	200/83 kHz	1	DP1.20086.001
Trimble GPS GEO XH 6000 or 7000	1 Hz; decimeter (10 cm/4 inch) accuracy positioning	1	DP1.20086.001

3.3   Product Instances

The equipment will be deployed to collect input variables at NEON lake and river sites. Bathymetry data will be collected every 5 years (at minimum) during the second biological sampling bout and during the period of peak greenness. Peak greenness is defined as the range of dates where MODIS NDVI is within 90% of the site maximum. Lake sites include:

- Domain 03 - SUGG and BARC
- Domain 05 - CRAM and LIRO
- Domain 09 - PRLA and PRPO
- Domain 18 - TOOK

Non-wadeable (river) sites include:

- Domain 03 - FLNT
- Domain 08 - BLWA and TOMB

3.4   Temporal Resolution and Extent

The finest temporal resolution at which bathymetric and morphological data are reported is the endDate, a single date on which survey data were collected. Bathymetric and morphological surveys are conducted at each lake and river site once every five years. Should an extreme event result in significant changes in water level, morphology, or habitat, an additional survey may be conducted sooner than every 5 years once safe conditions allow.

4   SCIENTIFIC CONTEXT

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, water quality, biogeochemical relationships, and biological productivity.

5   SOP IMPLEMENTATION

5.1   SOP 1. Bathymetric Map

5.1.1   Required Platforms and Tools

1. ArcMap 10.4.1 or later is required with extensions
   Geostatistical Analyst
   Spatial Analyst
   3D Analyst
2. ET Geo Wizards for ArcGIS 10.4+
3. SonarTRX - Version 17.1 (64 bit)+

5.1.2   Data Processing

SonarTRX

1. .DAT files are converted from the raw bathymetry data collected according to RD[04] to a csv using SonarTRX
   a. Open SonarTRX > Import > Browse Input File > Select .DAT file > Accept defaults > Start Processing
   b. Select Create Mosaic tab > Yes > Output Options tab > Check only Save Navigation Track (KML and XYZ file (Nav Track Profile.csv) > Start Processing
   c. Navigate in your computer browser to the Input file location
      i. Open "files" folder > Delete the "Logo" image file

ArcMap

2. Load Nav Track Profile.csv into ArcMap
   a. Open ArcMap > File> Add Data
3. Display xyz locations
   a. File > Add Data > Add XY Data
      i. X Field: Longitude
      ii. Y Field: Latitude
      iii. Z Field: ElevationBottom
      iv. Coordinate System of Input Coordinates > Edit > XY Coordinate System Tab > Geographic Coordinate Systems > World > WGS 1984 > OK > OK > OK
4. Export .csv Events file to shapefile
   a. Right click Events layer created in step 3.a > Data > Export Data
      i. Export: All features
      ii. Use the same coordinate system as: This layer's source data
      iii. Output feature class: tracks

    iv. Save as type: Shapefile

5. Add lake shore polygon using
  a. File > Add Data
6. Convert shore polygon file to point file
  a. ET GeoWizards Convert > Polygon to Point
    i. Select polygon layer > Shore Polygon shapefile
    ii. Specify output feature class or shapefile > Name: "shorePoints"
    iii. Save as type > Feature classes > Save > Next
    iv. Specify conversion option > Vertices > Finish
7. Assign Longitude, Latitude and Elevation to shorePoints.shp
  a. Add fields to shorePoints attribute table
    i. Right click shorePoints > Open Attributes Table > Add Field
      1. Selection Expression LONG
        a. Name: Longitude
        b. Type: Double
        c. Precision: 15
        d. Scale: 6
      2. Selection Expression LAT
        a. Name: Latitude
        b. Type: Double
        c. Precision: 15
        d. Scale: 6
      3. Selection Expression Elevation
        a. Name: Elevation
        b. Type: Double
        c. Precision: 15
        d. Scale: 3
8. Calculate Geometry for new attributes in shorePoints.shp
  a. Longitude
    i. Right click new Longitude field > Calculate Geometry
    ii. Property: X Coordinate of Point
    iii. Coordinate System: Use coordinate system of the data source: GCS: WGS 1984
    iv. Units: Decimal Degrees
  b. Latitude
    i. Right click new Latitude field > Calculate Geometry
    ii. Property: Y Coordinate of Point
    iii. Coordinate System: Use coordinate system of the data source: GCS: WGS 1984
    iv. Units: Decimal Degrees
  c. Elevation

      i. Right click new Elevation field > Field Calculator

      ii. Elevation = "0" > OK

9. Merge shorePoints.shp with tracks.shp and project to site specific UTM coordinate system

    a. ArcToolbox > Data Management Tools > General > Merge

      i. Selection Expression:

        1. Input Datasets: tracks, shorePoints

        2. Output Dataset: trackShorePointsMerge

        3. Field Map, remove all field except: Longitude (Double), Latitude (Double), ElevationBottom (Double)

          a. Environments…

            i. Output Coordinates

              1. Output Coordinate System

                a. As Specified Below: WGS 1984 UTM Zone xN > OK > OK

10. Interpolate data

    a. ArcToolbox > Geostatistical Analyst Tools > Interpolation > Empirical Bayesian Kriging

      i. Selection Expression:

        1. Input features: tracksShorePointsMerge

        2. Z value field: ElevationBottom

        3. Output geostatistical layer: optional

        4. Output raster: "SiteID_EBK.tif"

        5. Output cell: 1

        6. Data transformation type: EMPIRICAL

        7. Semivariogram model type: K_Bessel

          a. Environments…

            i. Raster Analysis

              1. Cell Size: Maximum of Inputs

              2. Mask: Lake Shore Polygon

            ii. Output Coordinates

              1. Output Coordinate System

                a. As Specified Below: WGS 1984 UTM Zone xN > OK > OK

11. Create Isobath contour lines (depth contour line at specified increments)

    a. ArcToolbox > 3D Analyst Tools > Raster Surface > Contour

      i. Selection Expression:

        1. Input raster: SiteID_EBK.tif

        2. Output polyline features: contour

        3. Contour interval: dependent on lake depth

          a. 0.5m contour for up to 5m depth

        b.   1m contour for up to 10m depth

        c.   2m contour for greater than 10m depth

    4.   Base contour: 0

    5.   Z factor: 1

12. Define Surface Volume

    a.   ArcToolbox > 3D Analyst Tools > Functional Surface > Surface Volume

        i.   Selection Expression:

            1.   Input Surface: SiteID_EBK.tif

            2.   Output Text File: volume

            3.   Reference Plane: ABOVE if values are positive; BELOW if values are negative

            4.   Plane Height: optional

            5.   Z Factor: 1

        ii.   Repeat step with total number of isobaths displayed in lake and merge all surface volumes into one file.

13. Visualization

    a.   Raster Prediction

        i.   Right click raster in Layers Table of Contents > Properties > Symbology tab

            1.   Show > Classified

                a.   Classify

                      i.   Classification Method = Defined Interval (identified in step 11.a.i.3) > OK

                b.   Color Ramp

                    i.   Right click to uncheck Graphic View

                      1.   Select Prediction > OK

    b.   Contour Labels

        i.   Right click Contour in Layers Table of Contents > Properties > Labels tab

            1.   Check box for Label features in this layer

            2.   Text String Label Field: CONTOUR > OK

5.2   SOP 2. Habitat Map

5.2.1   Required Platforms and Tools

1.   SonarTRX - Version 17.1 (64-bit)+

2.   ArcGIS - Version 10.4+

3.   Google Earth

5.2.2   Data Processing

SonarTRX

1. Download the recording files from the sonar unit's SD card. Place the .DAT file and the associated files in the RECORD folder.
2. Import Recording File into SonarTRX.
   a. Import > Navigate to .DAT file > Accept default parameters > Start Processing.
3. Slant Range Correction
   a. View and edit tab
      i. Channel > 0, 1 = down scan images, 2, 3 = left/sight side-scan sonar image
      ii. View > default Original (with water column)
      iii. Color Scheme > Blue turquoise
      iv. Inline stretch > Speed Corrected
      v. Display Altitude > Default
      vi. Range Limit > No limit
      vii. Click SRC/TVG tab
         1. Altitude Source (SRC) > Sensor Altitude
         2. Altitude adjust by > default 0.300 m
         3. Beam Angle Correction (BAC) > Automatic
         4. Start Processing > OK
      viii. View Results
         1. View dropdown > Slant Range Corrected
            a. Change Layout
               i. View Tab > Layout > Horizontal or Vertical (user preference)
4. Create Clips
   a. Nav tab > Start and stop tracks along straight track
      i. Click on track > Start Time > Select Tile
      ii. Click on track > End Time > Select Tile
      iii. New clip name > Descriptive name including location, date created, and clip number (e.g. BLWA_Date_clip1)
      iv. Append to list to save clip
      v. Repeat for additional clips
5. Export Imagery
   a. Close View and Edit Window > Select 3. Create Mosaic
   b. Browse > Location to save output imagery
   c. Add Mosaic Name
   d. Sonar Mosaic Settings
      i. Image resolution > 0.75

e. Output Options
  i. Checked boxes:
    1. Generate Mosaic Images and associated .kml files
      a. By default, show images
      b. Generate Projection file
      c. Generate Image Word files
    2. Generate Mosaic Coverage Areas and associated .kml files
      a. By default, Show coverage Areas
f. Start Processing…
g. Navigate to the mosaic imagery folder
  i. Open "files" folder > Delete the "Logo" image file

ArcMap

6. Import Imagery into ArcGIS
  a. Open ArcMap > Open ArcCatalog Window
  b. Navigate to working GIS folder
  c. Right click on folder > New > File Geodatabase > Name Geodatabase
  d. Create New Mosaic Dataset
    i. ArcToolbox > Data Management Tools > Raster > Create Mosaic Dataset (can be run as a Batch process with right click on tool > Batch)
      1. Output location: File Geodatabase created in step 6.c
      2. Mosaic Dataset Name: SonarTRX Recording File Name and Date
      3. Coordinate System: GCS WGS 1984
      4. OK
  e. Add Rasters to New Mosaic Dataset
    i. ArcToolbox > Data Management Tools > Raster > Mosaic Dataset > Add Rasters to Mosaic Dataset (can be run as a Batch process)
      1. Mosaic Dataset: Mosaic Dataset created in Step 6.d
      2. Raster Type: Raster Dataset
      3. Input Data: Workspace
      4. Navigate to folder with exported Sonar TRX imagery
        a. Select "files" folder
        b. Add
      5. OK
    ii.
  f. Build Footprints
    i. ArcToolbox > Data Management Tools > Raster > Mosaic Dataset > Build Footprints (can be run as a Batch process)
   1. Computational Method : RADIOMETRY

        2. OK

   g. Generate Seamlines

      i. ArcToolbox > Data Management Tools > Raster > Mosaic Dataset > Build Seamlines

        1.

        2. Computational Method: COPY FOOTPRINT

        3. OK

   h. Build Overviews

      i. ArcToolbox > Data Management Tools > Raster > Mosaic Dataset > Build Overviews (can be run as Batch process)

      ii. Keep defaults

      iii. OK

7. View imagery by loading mosaic datasets or .kmls into ArcMap and ground-truth data

   a. Identify

      i. Substrate

        1. Silt/clay

        2. Sand/gravel

        3. Cobble/boulders/bedrock

      ii. Vegetation presence

      iii. Large woody debris

      iv. Human (e.g. trash, fence, boat)

      v. Other

   b. Review collected ground-truth data that was entered into the mobile application along with other field data

      i. Import ground-truth location points

        1. File > Add Data

      ii. Identify each point with the information collected at each location

        1. Open Attribute Table

          a. Right click layer in Table on Contents

        2. Highlight 1st row > Right Click > Loom to Layer

   c. Compare mosaic imagery to ground-truth data and use ground-truth data to confirm habitat feature classifications

8. Create Habitat Polygons with symbology that represents substrate type, presence of vegetation, woody debris, human, or other

   a. Customize tab > Toolbars > Select Editor and Snapping

   b. Create new shapefile

      i. Right click on working GIS folder > New > Shapefile

        1. Name: Substrate

        2. Feature Type : Polygon

3. Spatial Reference > Edit > Projected Coordinate System > UTM > WGS84 > Northern Hemisphere > WGS 1984 UTM Zone xN >OK >OK

    c. Add Attributes field to new shapefile

        i. Right click on Substrate in Layers Table of Contents > Open Attribute Table

        ii. Click upper right icon for Table Options > Add Field

            1. Name: Habitat

            2. Type: Text

            3. Field Properties Length: 50 (default)

            4. OK

        iii. Click upper right icon for Table Options > Add Field

            1. Name: Area_m2

            2. Type: Double

            3. OK

9. Edit Habitat Polygons

    a. Click the drop down menu on the Editor toolbar > Start Editing

        i. Highlight Substrate file > OK

    b. Select Create Feature from Editor toolbar

        i. Create Features Window opens

    c. Click on Substrate Layer to activate editing tools

        i. Construction Tools > Select Polygon

        ii. On Snapping toolbar > Select Edge Snapping for straight line segments

    d. Use Straight Segment on Editor toolbar for straight independent lines

    e. Use Trace to align polygon with other features (shoreline, other polygons features)

        i. To pan while editing polygon hold C then click and drag

    f. Double click or hit F2 to finish polygon

    g. Add name of habitat type of completed polygon to attribute table

        i. Right click on Substrate in Layers Table of Contents > Open Attribute Table

        ii. Add name to row in "Habitat" column

    h. Repeat polygon creation for all substrate types

    i. Click Editor dropdown > Save Edits > Stop Editing

Table 3 - Habitat type and substrate classifications

Boulders	Large Woody Debris/Vegetation/Coarse Sand/Gravel
Clay	Large Woody Debris/Vegetation/Large Cobble/Boulder
Clay/Hard Substrate	Large Woody Debris/Vegetation/Silt

Coarse Sand/Gravel	Limestone Bedrock
Island	No Data
Large Cobble/Boulder	Sand
Large Cobble/Boulder/Silt	Sand/Soft Substrate
Large Woody Debris	Sand/Vegetation
Large Woody Debris/Boulders	Sandy Loam
Large Woody Debris/Clay/Hard Substrate	Silt
Large Woody Debris/Coarse Sand/Gravel	Sonar Shadow/No Data
Large Woody Debris/Large Cobble/Boulder	Undetermined
Large Woody Debris/Sand	Vegetation
Large Woody Debris/Sandy Loam	Vegetation/Coarse Sand/Gravel
Large Woody Debris/Sandy Loam/Vegetation	Vegetation/Large Cobble/Boulder
Large Woody Debris/Silt	Vegetation/Sand
Large Woody Debris/Silt/Large Cobble/Boulder	Vegetation/Silt
Large Woody Debris/Vegetation	

10. Join Shore Polygon and Habitat Substrate
    a. Open Arc Toolbox > Analysis Tools > Union
        i. Input Features: Substrate, Shore Polygon
        ii. Output Feature Class: DXXSITE_HABITAT_YYYYMMDD.shp
        iii. Join Attributes: ALL
        iv. Gaps Allowed: Unchecked
        v. OK
    b. Add remaining habitat type classification to attribute table
        i. Step 9.g
11. Calculate Area
    a. Right click on "Area_m2" attribute field > Calculate Geometry
        i. Property: Area
        ii. Coordinate System: Use PCS: WGS 1984 UTM Zone xN
        iii. Units: Square Meters [sq m]
        iv. OK
12. Calculate Frequency Statistics for Substrate Type
    a. Open Arc Toolbox > Analysis Tools > Statistics > Frequency
        i. Input Table: DXXSITE_HABITAT_YYYYMMDD.shp
        ii. Output Table: DXXSITE_HABITAT_YYYYMMDD area.csv
        iii. Frequency Field: Habitat
        iv. Summary Field: Area_m2
        v. OK

      b. Right click DXXSITE_HABITAT_YYYYMMDD area.csv in Table of Contents Layers > Open Attribute Table

            i. Table Options drop down > Add Field

                  1. Name: Percent_Cover

                  2. Type: Double

                  3. Field Properties

                        a. Precision: 0

                        b. Scale: 0

      c. Right click Area_m2 > Statistics > Highlight Sum > Right Click > Copy > X

      d. Right click Percent_Cover > Field Calculator

            i. Percent_Cover = ([Area_m2/Sum of Area{Paste from step 12.c})*100] > OK

6 UNCERTAINTY

Spatial datasets are not a seamless representation of real-world phenomena. Interpretation of the sonar images is inherently subjective and it is difficult to quantify uncertainty that may result. Level 0 data is also packaged and served to users so that they can potentially analyze the input data used to create bathymetry and habitat maps to better understand the uncertainty associated with the maps.

6.1 Sonar Unit

A Humminbird 1198c SI Combo sonar with an XHS 9 HDSI 180 T transducer with down imaging (dual beam 200/83 kHz) and side imaging sonar (455/800 kHz) are used to map NEON aquatic lakes and non-wadeable (river) reaches during bathymetric and morphology surveys.

6.2 Trimble GPS

A Trimble GeoXH 6000 or 7000 series GPS unit is used to collect GPS locations for the shoreline boundary, in-water features, and during ground truthing activities, throughout the bathymetric and morphology survey. Differential correction is applied during post-processing to improve GPS accuracy and reduce atmospheric errors by comparing the time signature at a fixed base station (typically CORS [Continuously Operating Reference Station]) near the rover file collected from the Trimble unit. The resulting file defines a horizontal and vertical accuracy using the root mean square error based on a 68% confidence level. NEON has aimed to utilize post-processed GPS positions that are within a horizontal and vertical precision of 10cm. Due to dense canopy at some sites and/or distance from base stations, not all GPS points surveyed fall within the desired range.