NEON ALGORITHM THEORETICAL BASIS DOCUMENT (ATBD): POST-PROCESSING OF STREAM MORPHOLOGY DATA FROM NEON WADEABLE STREAMS

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See configuration management system for approval history.

The National Ecological Observatory Network is a project solely funded by the National Science Foundation and managed under cooperative agreement by Battelle. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

Change Record

REVISION	DATE	ECO #	DESCRIPTION OF CHANGE
A	05/19/2025	ECO-07144	• Initial Release • Updated NEON logo

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1 DESCRIPTION

Contained in this document are details concerning the steps with which "raw" total station survey data, collected in the field, are transformed into the Level 4 data product "Stream morphology map" (DP4.00131.001). Geomorphology survey data are collected at all wadeable stream sites within the observatory according to AOS Protocol and Procedure: Wadeable Stream Morphology (RD[05]). Raw survey data, including total station outputs (also called POC outputs), are transformed into real-world coordinate system. Stream morphology data, including thalweg, habitat polygons, and geomorphic features, are created using ESRI software, fulcrum data, and survey notes. Summary statistics are provided for survey measurements with the use of standardized R scripts. Individual sites are surveyed on a 5-year rotation.

Additional surveys may take place due to sensor infrastructure maintenance on an as-needed basis (RD[07]). These surveys (called AIS Site Surveys) are also processed according to these procedures, albeit without many of the geomorphology-specific steps. AIS Site Survey data are provided with the "Stream morphology map" data product (DP4.00131001).

1.1 Purpose

This document details the procedures used for creating NEON Level 4 data products for "Stream morphology map" from Level 0 data. It includes a detailed discussion of measurement theory and implementation, appropriate theoretical background, data product provenance, quality assurance and control methods used, approximations and/or assumptions made, and a detailed exposition of uncertainty resulting in a cumulative reported uncertainty for this product.

1.2 Scope

The background and process used to derive Level 4 data from Level 0 data for "Stream morphology map" is described in this document. The survey instrument employed is the Hilti POS 180 mounted on a rugged leveling tripod. In coordination with a prism head, the Hilti POS 180 can simultaneously measure angles and distances to determine elevations and positions of points relative to the prism. Mapped points from the Hilti POS 180 are used to create the Level 4 data product "Stream morphology map" with methods found in this document. This document does not provide computational implementation details, except for cases where these stem directly from algorithmic choices 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.002652	NEON Data Products Catalog

2.2 Reference Documents

RD[01]	NEON.DOC.000008	NEON Acronym List
RD[02]	NEON.DOC.000243	NEON Glossary of Terms
RD[03]	Available with data download	NEON Raw Data Validation for Wadeable Stream Morphology (DP0.00131.001)
RD[04]	Available with data download	NEON Data Variables for Wadeable Stream Morphology (DP4.00131.001)
RD[05]	NEON.DOC.003162	AOS Protocol and Procedure: Wadeable Stream Morphology
RD[06]	NEON.DOC.001152	NEON Aquatic Sampling Strategy
RD[07]	NEON.DOC.005399	AIS Standard Operating Procedure: Conducting AIS Site Surveys at NEON Aquatic Sites
RD[08]	NEON.DOC.005221	AOS/TOS Standard Operating Procedure: Trimble GeoXH Receivers Setup and Use

2.3 External References

ER[01]	CRAN https://cran.r-project.org/web/packages/neonUtilities/ index.html
ER[02]	NEONUtilities Python Package Index https://pypi.org/project/neonutilities/
ER[03]	NEON Data Portal https://www.neonscience.org/download-explore-neon-data.
ER[04]	Transform features—ArcGIS Pro | Documentation https://pro.arcgis.com/en/pro-app/latest/help/editing/transform-a-feature.htm
ER[05]	NEON-geolocation Code Repository https://github.com/NEONScience/NEON-geolocation
ER[06]	NEON Locations API http://data.neonscience.org/data-api
ER[07]	NEON Stream Morphology Code Repository https://github.com/NEONScience/NEON-stream-morphology/tree/master

2.4 Acronyms

Acronym	Explanation
AIS	Aquatic Instrument System
AOS	Aquatic Observation System
ASCII	American Standard Code for Information Interchange

ATBD	Algorithm Theoretical Basis Document
CRAN	Comprehensive R Archive Network
COP	Control Point
CORS	Continually Operating Reference Station
DP	Data Product
GEO	Geomorphology
GCS	Geographic Coordinate System
GPS	Global Positioning System
HDOP	Horizontal of Dilution of Precision
HOPB	Hop Brook site in D01
ITRF	International Terrestrial Reference Frame
LEWI	Lewis Run site in D02
L0	Level 0
L4	Level 4
PDOP	Position of Dilution of Precision
RMS	Root Mean Square
TS	Total Station
UTM	Universal Transverse Mercator
WGS	World Geodetic System

2.5 Variable Nomenclature

N/A

3 DATA PRODUCT DESCRIPTION

The wadeable stream morphology data product provides data for three types of surveys at NEON aquatic sites. **Geomorphology surveys** are conducted at each site once every five years, on average. For a geomorphology survey, downloads include raw survey data and post-processed maps, shapefiles, and metric tables that quantify channel geomorphology, bed composition and biological habitat within the aquatic reach boundaries (approximately 1,000 meters in stream length) of NEON wadeable stream sites. Raw survey data are collected with high-resolution total station survey equipment at each site. Survey maps and channel metrics are produced by geo-referencing the raw survey data (Level 0) to a global coordinate system (Level 4). During years when a geomorphology survey is not conducted, a site will undergo a **rapid habitat assessment survey**. For a rapid habitat assessment survey, downloads include raw survey data and metric tables that assess habitat size and composition within the aquatic reach boundaries. Rapid habitat surveys do not utilize total station survey equipment and post-processing for this survey type is detailed in RD[08]. An **AIS (Aquatic Instrumented Systems) site survey** may also be conducted in any given year. For AIS site surveys, downloads include a table of survey points collected along one or more transects that bisect the stream channel. These data are used to delineate hydraulic controls for development of stage-discharge rating curves.

Survey type is distinguished in the surveyBoutTypeID field of geo_surveySummary. The other tables available through the download of this data product depend on the type of survey conducted. **Table 1** below provides a description of all tables available via download from the NEON Data Portal and from which survey type users should expect available data.

Geomorphology and rapid habitat assessment surveys are performed at wadeable stream sites only. AIS site surveys occur at wadeable streams as well as the inlet and outlet at Toolik Lake. Post processing steps below apply to geomorphology and AIS site surveys only (total station surveys).

3.1 Table 1Variables Reported

All variables reported from the field (L0 data) are listed in the file, NEON Raw Data Validation for Wade-able Stream Morphology (DP0.00131.001) (RD[03]). All variables reported in the published data (L4 data) are also provided separately in the file, NEON Data Variables for Wadeable Stream Morphology (DP4.00131.001) (RD[04]).

Field names have been standardized with Darwin Core terms (http://rs.tdwg.org/dwc/; accessed 16 February 2014), the Global Biodiversity Information Facility vocabularies (http://rs.gbif.org/vocabulary/gbif/; accessed 16 February 2014), the VegCore data dictionary (https://projects.nceas.ucsb.edu/nceas/projects/bien/wiki/VegCore; accessed 16 February 2014), where applicable. NEON AOS spatial data employs the World Geodetic System 1984 (WGS84) for its fundamental reference datum and GEOID12A (Conus, PuertoRico, or Alaksa depending on the site) for its geoid model. Latitudes and longitudes are denoted in decimal notation to six decimal places, with longitudes indicated as negative west of the Greenwich meridian.

Some variables described in this document may be for NEON internal use only and will not appear in downloaded data.

Table 1. Data tables available in downloads of the data product and the associated Survey Types.

Table	Description	Associated Survey Type
geo_featureInfo	Data associated with mapped cross-section transects	Geomorphology
geo_geomorphicFeatureCount	The type and total count of all geomorphic features mapped during the survey	Geomorphology
geo_mappedPointErrors	Data that describe any survey errors that need to be resolved during post-processing	Geomorphology
geo_misclosureInfo	Data associated with survey misclosure	Geomorphology
geo_missingLine	Data associated with the missing line workflow used to orient the first total station location during the survey	Geomorphology
geo_pebbleCount	Sediment particle size data collected during pebble count sampling	Geomorphology, Rapid Habitat
geo_pebbleFieldData	Sediment particle size distribution summary data associated with pebble count sampling during the survey	Geomorphology, Rapid Habitat
geo_processedSurveyData	Survey data generated during post processing, including point classifications and real-world coordinates	Geomorphology
geo_rapidHabitatAssessment	Data associated with the rapid habitat assessment portion of the stream morphology protocol	Rapid Habitat
geo_rawSurveyData	Raw data generated during the survey, including a unique identifier and raw coordinate values for each point mapped	Geomorphology
geo_surveyPoints	Data associated with mapped cross-section transects used to delineate hydrologic controls	Geomorphology, AIS Site Survey
geo_surveySummary	Summary data associated with the survey, including summary statistics such as survey completeness, physical channel characteristics, relationships between upstream and downstream sensor sets, and data download URLs	Geomorphology, Rapid Habitat, AIS Site Survey
geo_thalwegByHabitatID	Data that describe each stream habitat unit mapped during the survey	Geomorphology

geo_thalwegbyHabitatType	Summary level data for stream habitat units mapped during the survey	Geomorphology
geo_thalwegLongProfile	Data associated with points mapped on the streambed along the thalweg	Geomorphology
geo_totalStation	Data that describe each total station location setup, including control point and thalweg point identifiers, geomorphic features surveyd from each location, and associated error metrics	Geomorphology
geo_transectBankfullWidths	Data that describe channel widths measured at cross-section transects	Geomorphology
geo_trimbleData	Field collected spatial data	Geomorphology

Not all data tables associated with geomorphology surveys in **Table 1** will be available for every survey. Such opportunistic, but not required, tables for geomorphology surveys are as follows:

- **geo_mappedPointErrors**: Table will populate if errors occur during the survey that require edits during post-processing.
- **geo_missingLine**: Table will populate if the Missing Line workflow is conducted during the survey (see details in RD[05]).
- **geo_trimbleData**: Table will populate if Trimble GPS field data are collected during the survey.

For ease of table joining, each table published in this data product contains an identical eventID field formatted as the site ID followed by the year and month that constitutes the surveyEndDate (SITE.YYYYMM).

In addition to the data tables available in this data product via direct downloads from the NEON Data Portal, L4 and L0 data packages are available from cloud-stored locations using URL paths contained in direct download files (**Table 2**).

Table 2. Files available in cloud-stored L4 and L0 geomorphology survey data packages.

File Name	File Format	File Description
geomorphicFeaturePoints	.SHP	Shapefile that displays all geomorphic features delineated using single points (i.e. upstream/downstream waterfall boundaries and tributary locations)
geomorphicFeaturePolygons	.SHP	Shapefile that displays all geomorphic features delineated using polygons (multiple points) (i.e. mid-channel bars, islands, large woody debris jams, beaver dams, etc.)
habitatUnits	.SHP	Shapefile that displays habitat unit boundaries throughout the reach
sensors	.SHP	Shapefile that displays sensor set locations within the reach

File Name	File Format	File Description
thalweg	.SHP	Shapefile that displays thalweg line throughout the reach
transects	.SHP	Shapefile that displays transect locations throughout the reach
RAW data file	.SSF	Raw data collected on handheld Trimble receiver (AK sites or when permanent benchmarks are not used).
siteMap	.PDF	PDF map of the aquatic reach that features the reach boundary, transect, aquatic sensor, and staff gauge locations as well as biological habitat delineations along the thalweg line
siteMap	.KMZ	KMZ map of the aquatic reach that can be viewed using Google Earth software. This map features habitat unit delineations, sensor set and transect locations, the thalweg profile, and all geomorphic feature points and polygons mapped during the survey.
surveyNotes	.DOCX	Word file that documents site specifications, survey observations, and any deviations that occurred during the field survey
postProcessingNotes	.DOCX	Word file that documents site specifications and any deviations that occurred during post-processing

Geomorphology survey and rapid habitat assessment data consist of two separate download packages, which are stored and accessed differently. One set of files is available via download from the NEON data portal and includes all data tables. Shapefiles, maps, and unstructured data are downloaded from the cloud storage location via the URL provided in the geo_surverySummary table.

Data downloaded from the NEON Data Portal are provided in separate data files for each site and month requested. The *neonUtilities* package in R and the *neonutilities* package in Python contain functions to merge these files across sites and months into a single file for each table. The *neonUtilities* R package is available from the Comprehensive R Archive Network (CRAN; ER[01]) and can be installed using the install.packages() function in R. The *neonutilities* package in Python is available on the Python Package Index (PyPi; ER[02]) and can be installed using pip. For instructions on using the package in either language to merge NEON data files, see the Download and Explore NEON Data tutorial on the NEON website (ER[03]).

3.2 Input Dependencies

N/A

3.3 Product Instances

A minimum of one geomorphology survey will be conducted at each NEON aquatic site with a wadeable stream every five years. This will result in approximately seven geomorphology surveys per year across the NEON Observatory. One rapid habitat assessment will be conducted at each NEON aquatic site with a wadeable stream each year which there is not a geomorphology survey. AIS Site Surveys may occur when sensor infrastructure is repaired, redesigned, or moves from its last known location.

3.4 Temporal Resolution and Extent

Geomorphology surveys are conducted at each site once every five years (RD[06]).

AIS Site Surveys are conducted on an as needed basis according to RD[07]. Disruptions to sensor infrastructure or efforts to redesign existing sensor placement are some of the most common reasons for an AIS Site Survey to be implemented.

3.5 Spatial Resolution and Extent

A raw survey data file includes each of the individually mapped points collected by the total station during the geomorphology survey. These data are provided in the published “geo_rawSurveyData” table. Each point contains a relativeNorthing, relativeEasting, and relativeHeight coordinate that is relative to fixed benchmarks installed along the reach. Mapped points are distributed at a high resolution (typically less than 1m) throughout the extent of the aquatic reach. Points are mapped along the main channel to capture thalweg (or the deepest part of the stream) elevation, along the edge of water to capture wetted width, and along select transects that run perpendicular to the channel to capture cross-sectional area. Additional points are collected at stream features that locally influence fluvial processes (i.e. large woody debris jams, mid-channel bars, etc.).

RelativeNorthing, relativeEasting, and relativeHeight data contained in raw survey files are relative to a local Cartesian coordinate plane (X,Y, and Z, respectively) defined by the fixed benchmark used to orient the total station at the beginning of the survey. Fixed benchmark locations are globally referenced (WGS 84 reference coordinate system) and locally projected (UTM Zone x North) using global positioning instrumentation to an accuracy of 10-30 centimeters of elevation. The degree of additional uncertainty associated with each survey will vary and is dependent on operator error, site-specific conditions, and environmental factors. Uncertainty data associated with each survey are included within the data product package. During post-processing, GPS data are utilized to convert relativeNorthing and relativeEasting values to latitude, longitude, and elevation values to meters above mean sea level. All geo-referenced survey data are considered Level 4.

4 SCIENTIFIC CONTEXT

Fluvial geomorphology is the study of the form and function of streams and the interaction between streams and the landscape around them. The morphology of a stream is dynamic - changes in water level and sediment shape the channel and dictate how channel morphology responds to hydrodynamic forces. By characterizing the physical nature of the stream channel, the Stream morphology map data product provides important metrics to assess biological and physical processes in streams and how they change over time.

4.1 Theory of Measurement

Data associated with the Stream morphology map data product are collected using total stations, survey instruments that combine an electronic theodolite and an electronic distance meter to provide accurate measurements of both horizontal and vertical angles as well as distances. During each survey, channel dimensions are measured, and the boundaries of morphologic features and biological habitat are delineated. Each point mapped during the survey is assigned an identifier code by the surveyor and a horizontal and vertical distance from the total station relative to a fixed benchmark. These data are used to calculate metrics that describe the monitoring reach - such as channel slope and sinuosity, bankfull width, the type, count, and location of habitat units (e.g. riffles, runs, and pools) and the type, count, and location of geomorphic features (e.g., mid-channel bars and large woody debris jams). Spatial maps are also produced to provide a high-resolution characterization of the monitoring reach.

4.2 Theory of Algorithm

Equation 1. 2D Similarity transformation in ArcGIS (ER[04])

$$\begin{aligned} x' &= Ax + By + C \\ y' &= -Bx + Ay + F \end{aligned} \tag{1}$$

where:

A = *s* * cos *t*
B = *s* * sin *t*
C = Translation in *x* direction
F = Translation in *y* direction
s = Scale change (same in *x* and *y* directions)
t = Rotation angle, measured counterclockwise in xy-plane

Equation 2. RMS for latitude and longitude transformation

$$x_{RMS} = \sqrt{\frac{1}{n}(x_1^2 + x_2^2 + \ldots + x_n^2)} \tag{2}$$

where:

x = Residual error of fit for a single point
n = Number of links

Equation 3. Elevation transformation of survey points from a Trimble reference point

$$eM_P = (H_P - H_R) + eM_R \tag{3}$$

where:

eM = elevationM field
H = height field
R = Reference Trimble Point
P = Survey shot undergoing transformation

Equation 4. Calculation of Slope (calculated for Sensor Set and Total Thalweg lengths)

$$m = \frac{E_u - E_d}{L} * 100 \tag{4}$$

where:

m = Slope of stream
E = Elevation
u = Most upstream point
d = Most downstream point
L = Total length

Equation 5. Calculation of Channel Sinuosity Index

$$S = \frac{L_T}{d} \tag{5}$$

where:

S = Channel Sinuosity Index
L_T = Total length of thalweg
d = Straight line distance between the most upstream and downstream points of the reach

Equation 6. Calculation of Mean Bankfull Width

$$w = \frac{\sum d}{n} \tag{6}$$

where:

w = Mean bankfull width
d = Straight line distance between a transect's XS_LBF and XS_RBF survey points
n = Number of transects

5 ALGORITHM IMPLEMENTATION

The goal of post-processing of NEON Stream Morphology data is to produce consistently formatted and reproducible maps and data. The procedures required are described in this section.

Most sites have benchmark location data which is input to the POC prior to the start of a survey. These serve as reference points for the subsequently mapped survey points. Permanent benchmark locations and metadata data for transformations can be obtained from the geoNEON (ER[05]) R package function 'getLocBySite'.

1. Download the spatial data for the site of interest and then filter for locationType = "AOS benchmark named location type".
    a. The surveyPointID in the geo_rawSurveyData format is "BM_X" and is associated with the SITE.AOS.benchmark.X in the namedLocation column from getLocBySite.
    b. For example, surveyPointID "BM3" from a HOPB geo_rawSurveyData is associated with "HOBP.AOS.benchmark.3".

Spatial data can also be obtained using the NEON locations API (ER [06]). To search for the above example, use: http://data.neonscience.org/api/v0/locations/HOPB.AOS.benchmark.3.

Sites without permanent benchmarks require a transformation of the survey data to real-world coordinates (Section 5.3) using field collected spatial data. Trimble receivers are used to acquire positioning information.

Standardized R scripts are used to calculate statistics, create shapefiles, and add relevant metadata during the post-processing procedure. These scripts are given in **Table 3** and can be found in the NEON Stream Morphology Code Repository (ER[07]).

Table 3. R Scripts used during post-processing.

Script Name	Input	Output	Description
addShapefile Metadata.R	ThalwegMetrics ouput .shp files	.shp files with standard metadata	Adds metadata to shape file outputs with standardized metadata that includes usage and protocol information.
formatPOCOutputs.R	Raw POC .csv from field survey	Edited POC .csv	Formats raw field data from the POC to be compatible with ArcGIS and make subsequent processing steps easier.
geoThalwegMetricsAnd TableCreation2025.rmd	Manually created .shp files from the edited POC .csv	ThalwegMetrics tables and .shp files	Calculates statistics and creates shapefiles on manually created input files. Accounts for the bulk of script post-processing.
geoMorph TransectMetrics.rmd	ThalwegMetrics output .shp files	TransectMetrics tables	Calculates statistics on transects from ThalwegMetrics output files.

All surveys include a "postProcessingNotes" Word document, available for download from the L4 URL (located in the column "dataFilePath" of the survey summary .csv), which highlights anything noteworthy that was identified throughout the post-processing procedure.

5.1 Differential Correction

Since 2021, nearly all surveys use permanent benchmarks as the control points when setting up the first total station location. The benchmark names and locations are included as an input for the POC when starting the survey. Benchmark locations have had high resolution GPS data collected using Trimble receivers so they can serve as reference locations for the survey. The associated spatial data can be downloaded following instructions in section 5.

Due to permafrost heaving, sites in Alaska take GPS field measurements of newly established benchmark locations annually. "Raw" Trimble survey values are differentially corrected via GPS Pathfinder Office software according to AD[08]. Base Stations that provide the reference position for differential correction are within 200km of the sampled site.

- CORS (Continually Operating Reference Station) locations with ITRF (International Terrestrial Reference Frame) included in the name typically serve as the best reference stations.
- Base stations with L2 and G (GLONASS) signal frequencies are also prioritized.
- Base station data are verified for spatial and temporal coverage against the survey data.

Corrected position accuracies are reported and given in the output "geo_trimbleData" file. Data are then prepared for export as a positions-corrected ASCII table for manipulation in ArcGIS.

- Corrected positions are converted to UTM Coordinate System and the appropriate Zone for the location of the survey.
- The WGS 1984 Datum is utilized, altitude measured from Mean Sea Level, and GEOID12A (Conus, Alaska, or Puerto Rico) used for the Geoid Model.
- Coordinate and Altitude Units are reported in meters.

5.2 POC Output Re-formatting

The output from the raw field survey is re-formatted to be ArcGIS compatible with the use of the **formatPOCOutputs.R** script by:

- Delineating the POC output by ';' into readable columns.
- Removing unnecessary columns and adding on blank latitude, longitude, easting, northing, elevation, and mapCode columns to fill in later.
- Formatting each point with a standard mapCode value based on pattern matching from the surveyPointID field.
- Creating an onlyDigits field from the numeric values in the surveyPointID which can help with drawing of thalweg lines and habitat polygons.

Survey notes from the field data collection and the errors recorded in the Fulcrum app are then used to manually edit/delete any necessary surveyed points. Field survey point errors are given in the "geo_mappedPointErrors" output table.

- The most common edits needed are adjusted height values due to an issue with the Prism Rod Height or points to be deleted due to field error.
- Control Points (COPs) and Total Station (TS) sites are removed from the shot list at this processing stage.

5.3 ArcGIS Transformation

The relative easting, relative northing, and height of the raw total station survey points are transformed to real-world coordinates with a similarity transformation using the ArcGIS Transform tool per Equation 1.

Established monumentation points (either permanent benchmarks or the corrected outputs from Trimble data, herein referred to as benchmarks) with known spatial coordinates are also part of the total station survey (included as an input) and are used as the links to the transform the entire survey.

Benchmark locations are imported into ArcGIS along with the re-formatted raw survey data.

- Trimble-based temporary benchmark data are imported using GCS_WGS_1984 as the spatial reference.
- Total station survey data and permanently installed benchmarks spatial data are imported using WGS_1984_UTM_Zone_XX as the spatial reference (where XX is the appropriate UTM Zone for the surveyed location).
- Links are created between the benchmark points from the Total Station Survey layer (the source) and spatially referenced benchmark locations layer (the destination).
- After 2+ links are created, the Transform tool provides a Root Mean Square (RMS) Error that is later reported in the output 'geo_surveySummary' table. RMS is calculated per Equation 2.
    - The RMS error indicates how well the displacement links perform the intended transformation. Each displacement link generates a residual error that measures the fit between the location of the destination control point and the actual transformed location. The RMS error shown in the pane is the square root of the mean of the squares of the residual errors that are generated by each link.
- This process can also be performed using any survey points that are present in the Total Station Survey and have had real world spatial data collected (control points, plot markers, etc.).
- When possible, all benchmark locations are used to perform the transformation.

Elevation is transformed by editing the height of the survey points against the most accurate of the benchmark locations. The most accurate point is that which has the lowest vertical uncertainty, the lowest PDOP (Position of Dilution of Precision), and the lowest HDOP (Horizontal of Dilution of

Precision). The point with the highest accuracy is used as the reference elevation with which all other points are transformed according to Equation 3. The Elevation field is transferred from the Height field from the survey data.

5.4 Feature Classes

The following feature classes are created with ArcGIS: Geomorphic Features, Habitat, Perpendicular Lines, Sensor Box, and Thalweg. The 'surveyPointID' field in the geo_rawSurveyData table is used to create the corresponding feature classes.

5.4.1 Geomorphic Features

Geomorphic features are polygons created within the feature class by connecting corresponding survey points for each feature. Large Woody Debris (LWD), Mid-channel Bars (MCB) and Islands (ISL) are geomorphic features. For example: LWD_US, LWD_LB, LWD_RB, and LWD_DS (US – Upstream, LB – Left bank, RB – Right bank, DS – Downstream) are connected to form a polygon that approximates the spatial coverage of a large woody debris jam (**Figure 1**).

- Note that LWD_TOP points are spatially bound by the polygon but are not a constraining edge and as such are not used to define the polygon.
- Features are named in successive order, downstream to upstream.

Geomorphic feature points (i.e. TRB (tributary), BEA (beaver dam), etc.) are also recorded in the survey data and included in spatial maps but are not manually processed like the geomorphic feature polygons.

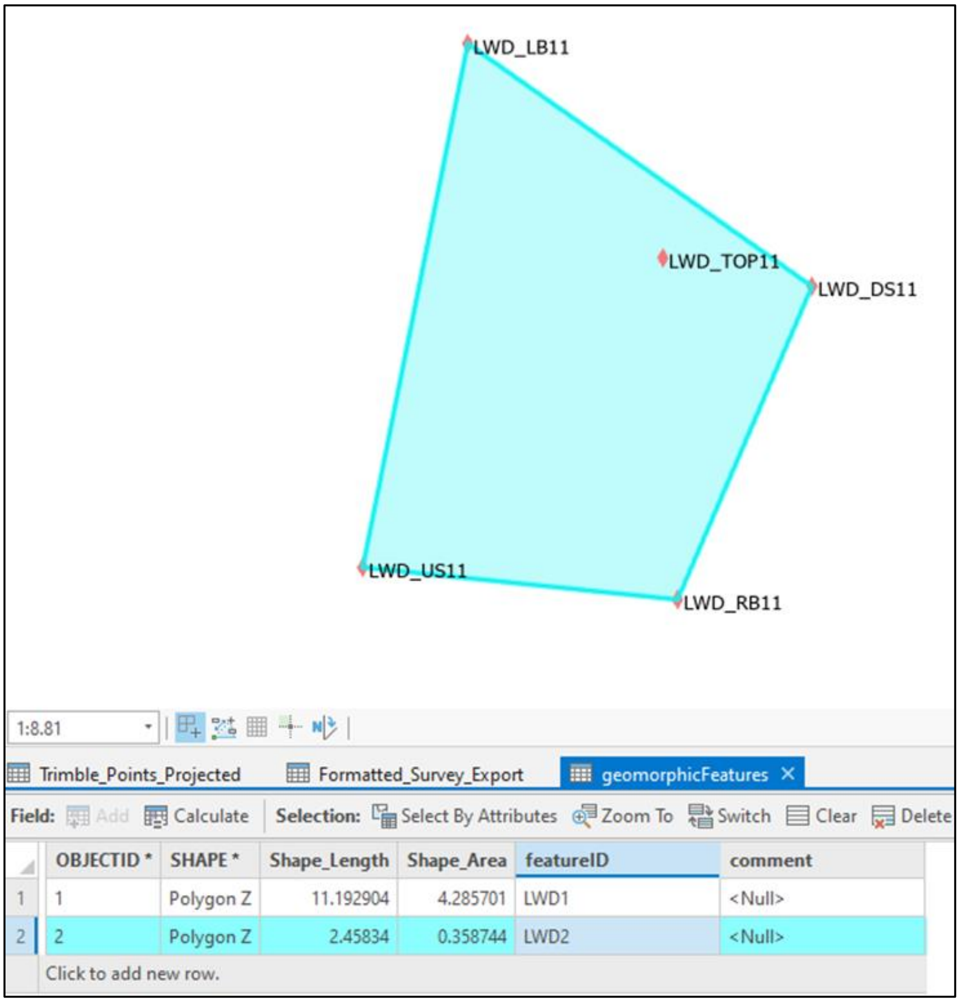

Figure 1. Mapping LWD Jam.

5.4.2 Thalweg

The Thalweg feature class contains a line which connects all surveyed THL (thalweg) points. The thalweg line consists of the thalweg points from the longitudinal survey as well as thalweg points identified in channel cross-sections (XS) and points of maximum pool depth (MPD). When split channels occur, two different thalweg lines are created and named for the geomorphic feature that causes the split (**Figure 2).** If no feature was mapped where a split channel occurs, the lines are given the name "BraidedChannel#".

If the survey was conducted when portions of the stream were dry, those portions are given their own section of the Thalweg line where the dryComment field = Y. These line up with the upstream and downstream thalweg lines so that there is a continuous thalweg throughout the reach. Dry sections do not have associated habitatIDs. The dryComment field is used to remove sections of the thalweg for downstream processing. If the entirety of the reach is dry during a survey, most subsequent calculations cannot be completed and percentDry is given as 100%.

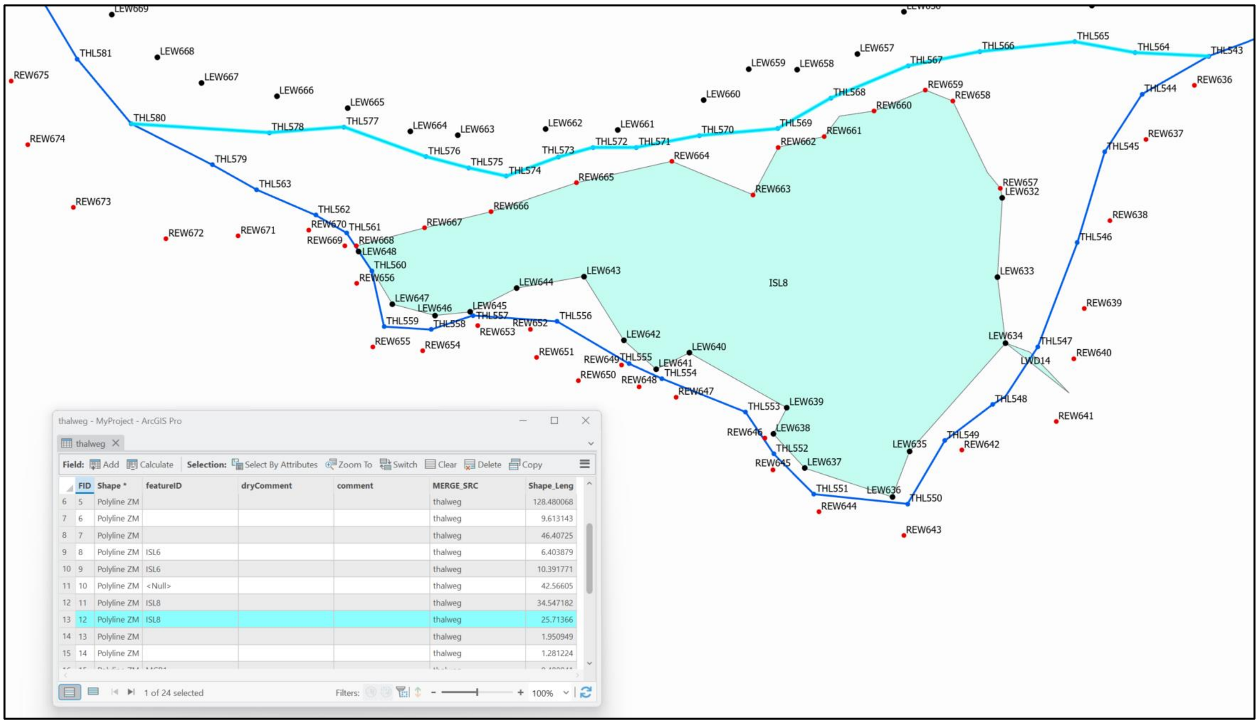

Figure 2. Thalweg creation around a geomorphic feature.

5.4.3 Habitat

Habitat features are created which separate the stream into its habitat components as identified by the surveyors with habitat tail points (i.e. POT (pool tail), RIT (riffle tail), RUT (run tail), etc.). Habitat tails are the location where the upstream extent of one habitat unit meets the downstream extent of a different habitat unit. These are named according to the upstream habitat unit for which this point marks the downstream extent.

An extension of the tail points is needed to serve as the downstream and upstream ends of the habitat unit. This extension is created as a temporary feature class, Perpendicular Lines. The Perpendicular Lines features start at the habitat tail and extend outwards toward the left and right bank perpendicular to the angle of the corresponding thalweg line to standardize habitat polygon creation (Figure 3).

Using the perpendicular line as the habitat tail, successive REW (Right Edge of Water) points are connected to start the habitat polygon. The polygon continues to the next upstream perpendicular line (indicating a change in habitat), and circles back along successive LEW (Left Edge of Water) shots (or vice versa) until returning to the initial habitat tail line.

- Habitat IDs are named starting from downstream to upstream.

- In the rare instance that Habitat polygons do not include a portion of the Thalweg feature class, vertices of the habitat polygon are shifted slightly to ensure full coverage of the thalweg.
- If a subterranean section was mapped during the survey, a feature class is not created but the length and associated habitat ID are recorded for later exclusion from processing.

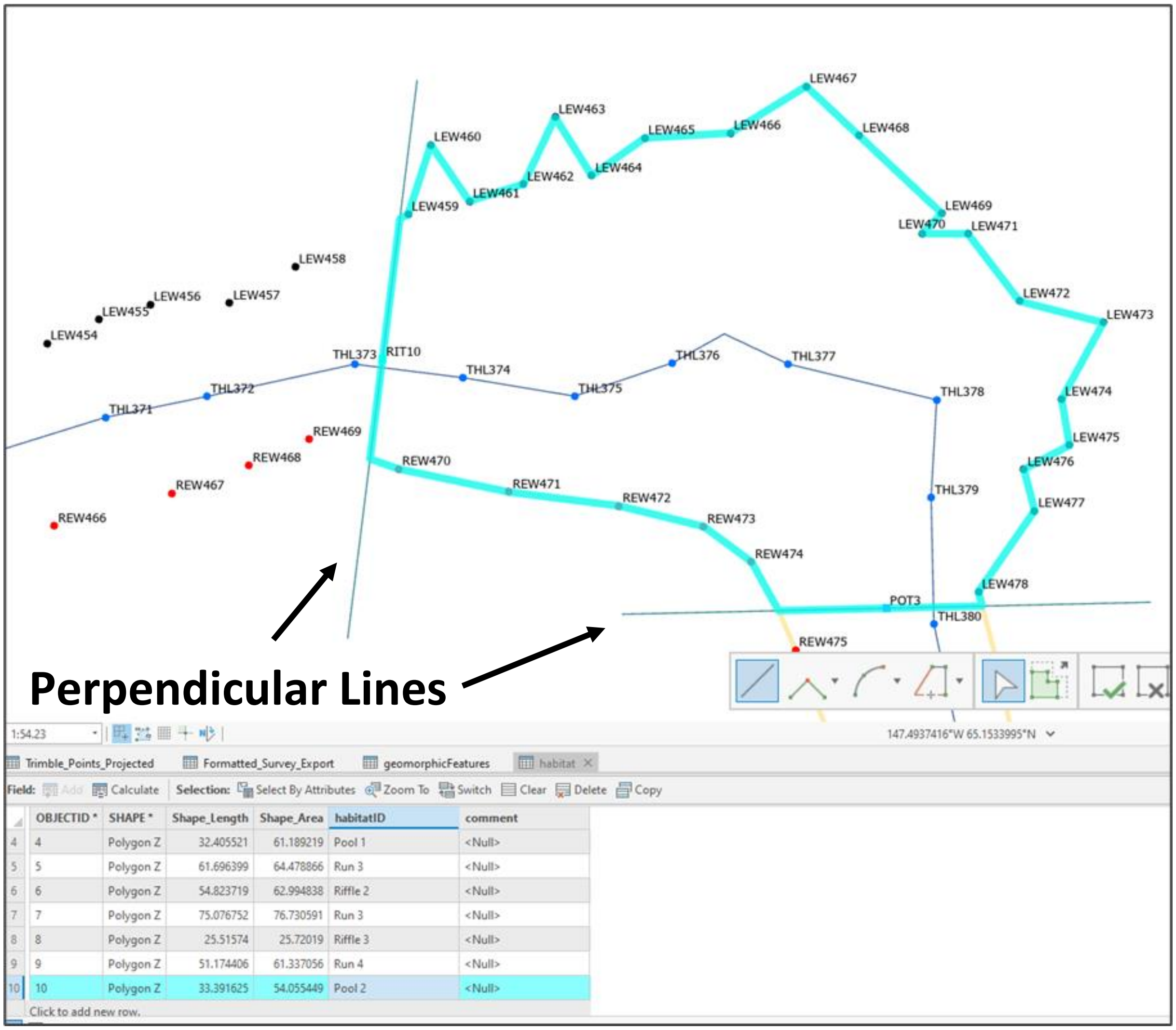

Figure 3. Habitat features creation using Perpendicular Lines and REW/LEW survey shots.

If the survey was conducted when a section of the stream was dry and no habitatID was recorded, a flat, one meter buffer is drawn around the thalweg at those thalweg locations marked where dryComment = Y. This serves as the habitatID for dry sections and are labeled as “drySection#” with a comment “Creek was dry in this section during the survey”. Dry section habitatIDs are connected to the downstream or upstream habitat polygons so that there is an overlapping polygon over all sections of the recorded thalweg. Surveys can be completed where the entire reach is dry and thus only have one long buffered habitat polygon surrounding the thalweg.

5.4.4 Sensor Box

The Sensor Box polygon feature class is a temporary polygon that contains the morphological features between the sensor sets are characterized in later calculations. This feature class is created to serve as bounds which include all surveyed points downstream of sensor set 1 and upstream of sensor set 2.

5.5 Statistics R-Scripts

All created feature class files are exported as shape files. Scripts given in **Table 3** are used to perform analysis on the exported feature classes. Once all shape files are created, the **geoThalwegMetrics AndTableCreation2025.rmd** script is used to generate summary tables and additional shape files. Then, **geoMorphTransectMetrics.rmd** is used to generate statistics related to individual transects captured during the survey. These scripts can be implemented by specifying the location of the input shape files and tables in a local directory.

Output shape files from the **geoThalwegMetrics** script are then given appropriate metadata with the **addShapefileMetadata.R** script.

5.6 Map Creation

Standardized maps are created for each survey using outputs from the R-scripts mentioned in the previous section. These are given in the form of PDF and KMZ maps.

The following shapefiles are used to create the maps:

- geomorphicFeaturePoints (kmz only)
- geomorphicFeaturePolygons (kmz only)
- habitatUnits (pdf only)
- sensors
- thalweg
- transects
- habitatUnitsKMZ (kmz only)
- In addition, the aquatic reach boundary is added from NEON ArcGIS Online

The ArcGIS Geoprocessing tool “Map to KML” is used to convert the contents of the ArcGIS data frame to .kmz format. Standardized icons and colors are used to signify geomorphic features, transects, sensors, habitat, and thalweg features.

The PDF map is created with the sampling site’s county included as a second data frame for a map inset (**Figure 4**). The Map Layout is exported as a Flattened PDF to reduce file size. The geomorphic features are not included since they are often hard to see with the scale of the reach.

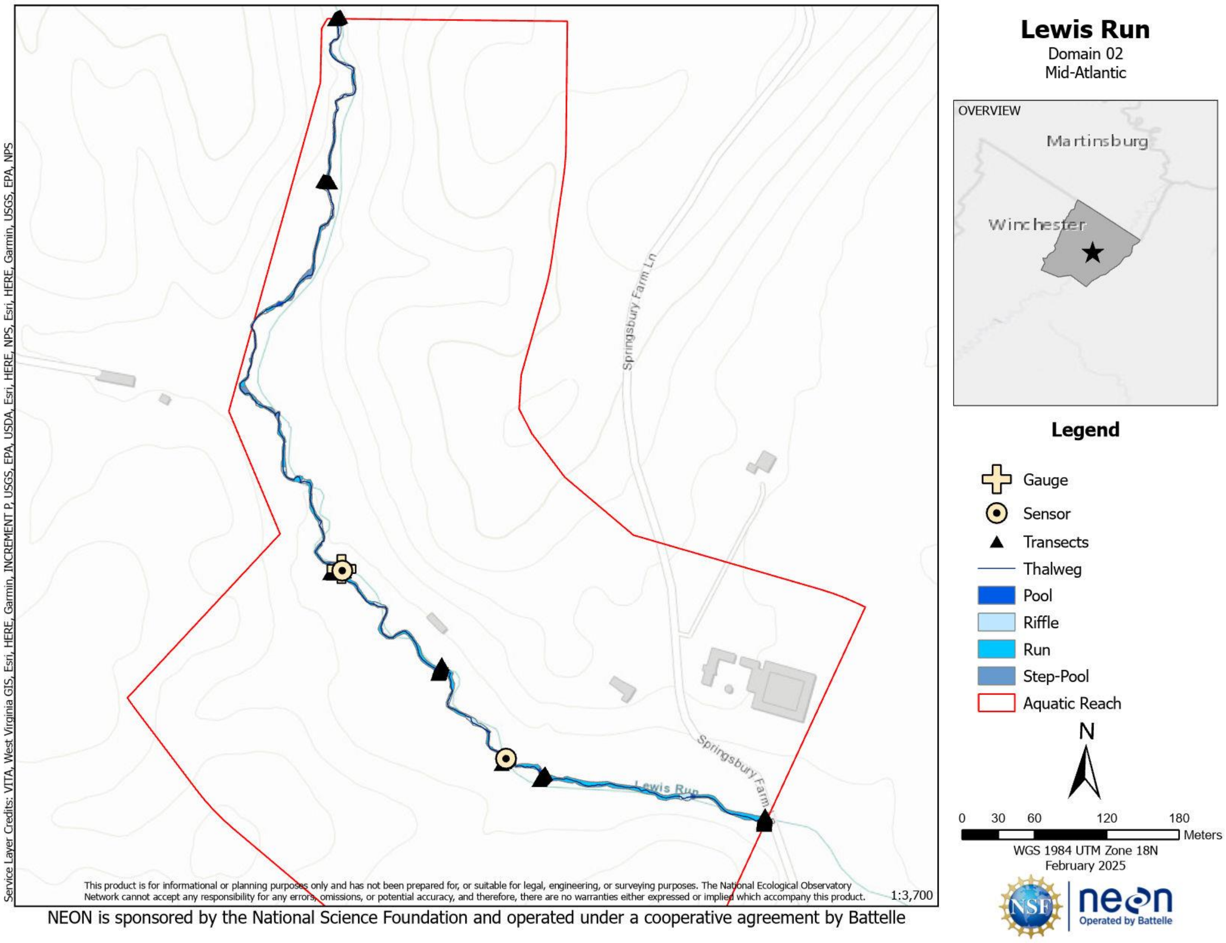

Figure 4. Example standardized PDF Map (LEWI_20241126).

5.7 QA/QC Procedures

A factory calibration of the total station is required within one year leading up to the stream morphology survey. Additionally, a field calibration is performed within one month prior to the start of the survey, including calibration of the prism head, prism rod, and total station.

QA/QC checks are performed on stream morphology survey data at various stages of data collection and processing. Field data collection uses a Fulcrum application, where input values are constrained. Mapped points that contain errors are documented in the field application and removed or edited during post-processing. Code-driven checks are performed on all surveys completed each year, confirming timeliness, completeness, and plausibility of the data.

6 UNCERTAINTY

Spatial datasets are not a seamless representation of real-world phenomena. Spatial uncertainty varies within each survey and is reported within the metadata package (aos_stream_morphology_prod_station .csv) and within the L4 data package (geo_trimbleData and the metadata associated with the permanent benchmarks from the locations API).

A HILTI POS 180 Robotic Total Station and POC data collector are used to spatially map the aquatic reach during geomorphology surveys. The POS 180 contains angle measurement accuracy (DIN 18723) of 3", a distance measurement accuracy pf +- 2 mm + 2 ppm and a magnification of 31x. The measurement range of the instrument is 79" to 9843'. Station deviation values are reported and documented for each total station setup throughout the survey. The best effort is made to minimize station deviations to <= 0.005m per total station setup, however this is not always possible given certain site conditions (i.e. unstable ground surfaces or extreme weather). Total station deviation values for each setup are included in the geo_totalStation table as well as well as benchmark misclosure values in the geo_misclosureInfo table. Misclosure values can be utilized to assess uncertainty associated with each survey. The benchmark locations shot during the beginning of the survey will have slightly different spatial coordinates at the end of the survey. This deviation is termed misclosure. As error builds in subsequent total station locations, the cumulative error can be understood using misclosure information.

A Trimble GeoXH 6000 or a 7000 series GPS unit with Tornado antenna is used to collect survey grade GPS locations at benchmarks or control points throughout the geomorphology 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]) nearby the rover file 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.

Transformation error values are reported per survey in the geo_surveySummary table 'total TransformationError' error field.

6.1 Expanded Uncertainty

N/A

6.2 Uncertainty Budget

N/A

7 FUTURE PLANS AND MODIFICATIONS

GPS receivers will be replaced as current Trimble GeoExplorer 6000 and Geo7X handheld units and associated software reach their end-of-life timeline. New hardware and software uncertainty values will be published as reported.

8 BIBLIOGRAPHY

N/A