NEON ALGORITHM THEORETICAL BASIS DOCUMENT (ATBD): WATERSHED DELINEATION FOR NEON AQUATIC SITES

PREPARED BY	ORGANIZATION	DATE
Melissa Slater	SCI	12/07/2020
Victoria Waits	NEON	12/02/2019
John Musinsky	AOP	01/13/2020

APPROVALS	ORGANIZATION	APPROVAL DATE
Kate Thibault	SCI	05/26/2022

RELEASED BY	ORGANIZATION	RELEASE DATE
Tanisha Waters	CM	05/26/2022

See configuration management system for approval history.

Change Record

REVISION	DATE	ECO #	DESCRIPTION OF CHANGE
A	07/16/2020	ECO-06418	Initial Release
B	12/21/2020	ECO-06543	Two new taxa included in variables list Table 3 for soil order classifications. Update to Table 8 with additional soil data source. Update to Section 4.2 to include NLCD dates source and NRCS resolution.
C	05/26/2022	ECO-06832	• Update to reflect change in terminology from relocatable to gradient sites

TABLE OF CONTENTS

LIST OF TABLES AND FIGURES

1 DESCRIPTION

1.1 Description

Contained in this document are details concerning the algorithm for creating Level 4 (L4) spatially rectified watershed hydrology data of NEON aquatic field sites using ArcGIS Pro 2.4.0. Specifically, the process for converting elevation data into delineated watersheds.

1.2 Purpose

This document details the algorithms used for creating NEON Level 4 spatially rectified watershed hydrology boundaries from Level 3 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.

1.3 Scope

This document describes the theoretical background and entire algorithmic process for deriving watershed boundaries from input data. It 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 (NOD) Requirements
AD[02]	NEON.DOC.002652	NEON Level 1-3 Data Products Catalog
AD[03]	NEON.DOC.005005	NEON Level 0 Data Products Catalog
AD[04]	NEON.DOC.002390	NEON Algorithm Theoretical Basis Document (ATBD): NEON Elevation (DTM and DSM)
AD[05]	NEON.DOC.001984	AOP Flight Plan Boundaries Design
AD[06]	NEON.DOC.003601-3618	Aquatic Site Sampling Design – NEON Domain 01-19

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.0005011	NEON Coordinate Specification
RD[04]	NEON.DOC.001292	NEON L0-to-L1 Discrete Return LiDAR Algorithm Theoretical Basis Document (ATBD)
RD[05]	NEON.DOC.002293	NEON Discrete LiDAR Datum Reconciliation Report

2.3 External References

ER[01]	Dean B. Gesch et al., "The National Elevation Dataset" (American Society for Photogrammetry and Remote Sensing, 2018). https://pubs.er.usgs.gov/publication/70201572
ER[02]	Dean B. Gesch et al., "Accuracy Assessment of the U.S. Geological Survey National Elevation Dataset, and Comparison with Other Large-Area Elevation Datasets: SRTM and ASTER," USGS Numbered Series, Open-File Report (Reston, VA: U.S. Geological Survey, 2014). http://pubs.er.usgs.gov/publication/ofr20141008
ER[03]	(Toolset) Arc Hydro Installation - Versions and Documentation, GeoNet, The Esri Community. Tutorial Version 2.0, October 2011, Arc Hydro Version ArcHydroPro2.0.43, September 2019. https://community.esri.com/message/393615-arc-hydro-installation-versions-and-documentation
ER[04]	(Dataset) U.S. Geological Survey, National Geospatial Program, The National Map, 3D Elevation Program, Elevation Products, 1/3 arc-second DEM, TNM Download. https://viewer.nationalmap.gov/basic/
ER[05]	(Dataset) Multi-Resolution Land Characteristics Consortium (MRLC 2018), National Land Cover Database (NLCD 2011). https://data.nal.usda.gov/dataset/national-land-cover-database-2011-nlcd-2011

ER[06]	(Dataset) U.S. Department of Agriculture, Natural Resources Conservation Service, Web Soil Survey Gridded Soil Survey Geographic (SSURGO) Database. https://websoilsurvey.nrcs.usda.gov/
ER[07]	(Software) ESRI 2019. ArcGIS Pro: Release 2.4. Redlands, CA: Environmental Systems Research Institute. https://www.esri.com/en-us/arcgis/products/arcgis-pro/overview
ER[08]	Goulden, T., C. Hopkinson, R. Jamieson, and S. Sterling. 2014. "Sensitivity of Watershed Attributes to Spatial Resolution and Interpolation Method of LiDAR DEMs in Three Distinct Landscapes." Water Resources Research 50 (3): 1908–27. https://doi.org/10.1002/2013WR013846
ER[09]	Amatya, Devendra, Carl Trettin, Sudhanshu Panda, and Herbert Ssegane. 2013. "Application of LiDAR Data for Hydrologic Assessments of Low-Gradient Coastal Watershed Drainage Characteristics." Journal of Geographic Information System. 5(2): 175-191 5 (2): 175–91. https://doi.org/10.4236/jgis.2013.52017
ER[10]	Chow, T. Edwin, and Michael E. Hodgson. 2009. "Effects of Lidar Post-spacing and DEM Resolution to Mean Slope Estimation." International Journal of Geographical Information Science 23 (10): 1277–95. https://doi.org/10.1080/13658810802344127
ER[11]	Goulden, T. and C. Hopkinson. 2010. "The forward propagation of integrated system component errors within airborne lidar data." Photogrammetric Engineering and Remote Sensing. 76(5), 589-601. https://doi.org/10.14358/PERS.76.5.589
ER[12]	Geological Survey and U.S. Department of Agriculture, Natural Resources Conservation Service, 2013, "Federal Standards and Procedures for the National Watershed Boundary Dataset (WBD)" (4 ed.): Techniques and Methods 11–A3. https://pubs.usgs.gov/tm/11/a3/
ER[13]	(Dataset) U.S. Department of Agriculture, Natural Resources Conservation Service, U.S. General Soil Map, State Soil Geographic Database (STATSGO2). https://websoilsurvey.nrcs.usda.gov/

2.4 Acronyms

Acronym	Explanation
AIS	Aquatic Instrument System
AOP	Airborne Observation Platform
AOS	Aquatic Observation System
ATBD	Algorithm Theoretical Basis Document
DEM	Digital Elevation Model
DP	Data Product
DTM	Digital Terrain Model
GNIS	Geographic Names Information System
L3	Level 3
L4	Level 4
LiDAR	Light Detection and Ranging
MRLC	Multi-Resolution Land Characteristics Consortium
NCSS	National Cooperative Soil Survey

NED	National Elevation Dataset
NLCD	National Land Cover Database
NRCS	Natural Resources Conservation Service
NSSDA	National Standard for Spatial Data Accuracy
QA/QC	Quality assurance and quality control
SSURGO	Soil Survey Geographic database
TNM	The National Map
USDA	United States Department of Agriculture
USGS	United States Geological Survey
UTM	Universal Transverse Mercator
WGS84	World Geodetic System 1984

2.5 Variables

2.5.1 Watershed Delineation

Table 1. Watershed Variables

File	File Type	Process	Variable	Description
elevation.tif	raster	Input	DEM	10 meter DEM elevation raster file(s) downloaded from USGS TNM Download.
DTM.tif	raster	Input	DTM	1 meter DTM elevation raster file(s) downloaded from NEON Data Portal.
Fil raster	raster	Output	Fill	Elevation manipulation to fill errors (low points (e.g. sinks)) in the raster data
Fac raster	raster	Output	Flow Accumulation	Weighted value raster of cells flowing into each down slope cell.
Fdr raster	raster	Output	Flow Direction	Value raster of cell direction flowing from steepest to downslope neighbor.
Cat raster	raster	Output	Catchment	Area of contributing cells above a reference point/cell.
Strlnk raster	raster	Output	Stream Link	Raster grid of unique stream segments defined as either head segments (the most upstream stream branch), or segments located between two segment junctions.
Str raster	raster	Output	Stream	Raster of streams defined by a threshold drainage area.

Catchment.shp	shapefile	Output	Catchment	Polygon shapefile that defines zones of cells whose drainage flows through each stream link.
AdjointCatchment.shp	shapefile	Output	Adjoint Catchment	Polygon shapefile of aggregated upstream catchments.
DrainageLine.shp	shapefile	Output	Drainage Line	Line shapefile of drainage system derived from the stream link grid.
DrainagePoint.shp	shapefile	Output	Drainage Point	Point shapefile of drainage at the most downstream point in the catchments.
PourPoint.shp	shapefile	Output	Pour Point	Output point shapefile of the lowest point along the boundary of the local watershed.
Watershed.shp	shapefile	Output	Watershed	Polygon shapefile of the total area flowing to the pour point.
WatershedPoint.shp	shapefile	Output	Watershed Point	Point shapefile of the point at which water flows out of an area.

2.5.2 Land Use

Table 2. NLCD Land Use Classification

Watershed Attribute Table Abbreviation	Classification Description	Classification Number
NLCD_11	Open Water	11
NLCD_12	Perennial Ice/Snow	12
NLCD_21	Developed, Open Space	21
NLCD_22	Developed, Low Intensity	22
NLCD_23	Developed, Medium Intensity	23
NLCD_24	Developed, High Intensity	24
NLCD_31	Barren Land (Rock/Sand/Clay)	31
NLCD_41	Deciduous Forest	41
NLCD_42	Evergreen Forest	42
NLCD_43	Mixed Forest	43
NLCD_51	Dwarf Scrub	51
NLCD_52	Shrub/Scrub	52
NLCD_71	Grassland/Herbaceous	71
NLCD_72	Sedge/Herbaceous	72
NLCD_74	Moss	74
NLCD_81	Pasture/Hay	81
NLCD_82	Cultivated Crops	82
NLCD_90	Woody Wetlands	90

NLCD_95	Emergent Herbaceous Wetlands	95
NLCDNoData	NA	NA

2.5.3 Soil

Table 3. NRCS Soil Taxonomy Order Classification

Watershed Attribute Table Abbreviation	Soil Classification Orders	Soil Classification Abbreviation
NRCS_ALF	Alfisols	ALF
NRCS_ARI	Aridisols	ARI
NRCS_AND	Andisols	AND
NRCS_ENT	Entisols	ENT
NRCS_GEL	Gelisols	GEL
NRCS_HIS	Histosols	HIS
NRCS_INC	Inceptisols	INC
NRCS_MOL	Mollisols	MOL
NRCS_OXI	Oxisols	OXI
NRCS_SPO	Spodosols	SPO
NRCS_ULT	Ultisols	ULT
NRCS_VER	Vertisols	VER
NRCS_WATER	NA (Water)	NA
NoSoilData	NA	NA

2.5.4 Variables Reported

Table 4. Watershed Output Variables Reported

Watershed Attribute Table Name	Description of Attribute
DATA	States if the watershed was not derived from NEON data, these sites are supplemented with the 10 meter National Elevation Dataset.
Area_NED	Watershed area in kilometers squared for sites where the watershed was derived from the 10 meter National Elevation Dataset.
WSAreaKm2	Watershed area in kilometers squared for watersheds derived from NEON's 1 meter Elevation-LiDAR dataset.
DomainNum	NEON ecoclimatic domain number.
DomainName	NEON ecoclimatic domain name.
SiteName	NEON aquatic site name.
SiteID	NEON four character site ID for the aquatic site.
SiteType	Type of NEON site (e.g. core aquatic or gradient aquatic).

Science	Identifies the primary science theme as they relate to the NEON Grand Challenges (AD[01]) and if the aquatic site is a wadeable or non-wadeable stream, or lake.
StateID	The 2 letter abbreviation for the state where the watershed is located.
HUC12Name	Name of the Hydrologic Unit Code with twelve digits based on the prominent water or physical feature(s) within the unit. Naming follows the conventions and rules outlined by the Geographic Names Information System (GNIS) order of priority and if the dominant feature is named in the HU10, the HU12 retains the twelve digit code as the name (ER[12]).
HUC12	Hydrologic Unit Code with twelve digits based on the sixth-level (subwatershed) classification designated by the United States Geological Survey (ER[12]).
TIS_Dist	Distance in kilometers from the aquatic site pour point to the corresponding terrestrial tower site.
TIS_Bear	Bearing in degrees from the aquatic site pour point to the corresponding terrestrial tower site.
TIS_WS	States if the corresponding terrestrial tower is within the aquatic watershed.
AOPLiDAR	Name of the Elevation-LiDAR DTM tile from the NEON data portal, includes site ID, year, and month the data was collected.
AOP_Flight	Identifies the NEON AOP Flight Boundaries layer showing the extent and priority of airborne acquisition.
AOPCoverag	Identifies the percent coverage of the NEON AOP flight box over the aquatic watershed.
UTM_Zone	The local projected coordinate system for the aquatic site and model processing.
NLCD_(number)	Percentage of land cover classifications within the watershed from the National Land Cover Dataset (NLCD) (Table 2).
NRCS_(Soil abbreviations)	Percentage of soil classifications within the watershed from the Natural Resources Conservation Service (NRCS) (Table 3).

3 DATA DESCRIPTION

Watershed delineation incorporates multiple input and output files to derive an area of land that captures surface drainage, land use, and soil characteristics impacting Aquatic Instrumentation Systems (AIS) and Aquatic Observation Sampling (AOS) at NEON aquatic field sites.

3.1 Input Dependencies

3.1.1 Elevation Data

Table 5. Elevation Model

Input	File type	Description
1m DTM	raster	1 meter resolution Digital Terrain Model (DTM) produced by NEON Elevation-LiDAR data product (DP) AD[02]
10m DEM	raster	10 meter resolution Digital Elevation Model (DEM) provided by USGS National Elevation Dataset (NED) ER[04]

3.1.2 AIS Sensor Locations

Table 6. AIS Sensor

Input	File type	Description
Outlet Sensor	shapefile	In-situ sensor located at lake outlet
S1 Sensor	shapefile	In-situ sensor location used for non-wadeable streams
S2 Sensor	shapefile	In-situ sensor location used for wadeable streams

3.1.3 Land Use Data

Table 7. NLCD Land Use Classification

Input	File type	Description
NLCD	shapefile	2016 National Land Cover Database (NLCD) ER[05]

3.1.4 Soil Map Units

Table 8. NRCS Soil Classification

Input	File type	Description
SSURGO	shapefile	Soil Survey Geographic Database (SSURGO) ER[06]
STATSGO2	shapefile	State Soil Geographic Database (STATSGO) ER[13]

3.2 Product Instances

One watershed was delineated for each of the 34 NEON aquatic sites. Watershed shapefiles and maps are provided on neonscience.org and neon.maps.arcgis.com.

3.3 Temporal Resolution and Extent

LiDAR data gathered from NEON's Airborne Observation Platform (AOP) were used to derive 1 meter resolution watersheds. LiDAR data from these flights were collected during the >90% peak greenness of dominant vegetation at each site between 2016-2019 (AD[05]).

DEM data provided by the USGS National Elevation Dataset (NED) (ER[01]) were used to derive 10 meter resolution watersheds. Data acquisition for the NED range from 2013 to 2019 (ER[04]).

As additional LiDAR data become available from future airborne observation flight campaigns, the LiDAR derived watersheds may be updated and revised.

3.4 Spatial Resolution and Extent

Watersheds derived from 1 meter resolution DTM provided by NEON range in size from 0.57 km^2 to 120.40 KM2. For a small portion of the aquatic sites, NEON's AOP Elevation - LiDAR data product (DP3.30024.001) did not cover the entire aquatic watershed (AD[05]). Where NEON LiDAR data did not provide complete watershed coverage, the 10 meter DEM was used to model the watershed. Watersheds derived from 10 meter resolution DEM provided by USGS NED range in size from 6.34 KM2 to 47085.35 KM2. Each of the 34 aquatic sites have one final, complete watershed produced with either the LiDAR DTM or the National DEM.

4 SCIENTIFIC CONTEXT

Hydrological drivers, weather, climate, biogeochemistry, and seasonal biological transitions are important drivers and indicators of aquatic ecosystem function. At each aquatic field site, the NEON project collects data to understand changes in climate, hydrology, biogeochemical processes, organismal populations, and habitat structure. Hydrology models reveal how water flows across surface areas. Watershed delineation, based on high-resolution elevation models, produce lower stream network and stream density error estimates. This results in higher spatial accuracy when modeling across low-gradient to moderately sloping terrain (ER[08], ER[09], ER[10]). When paired with other NEON meteorological, surface, and subsurface hydrologic data, these watershed layers can aid in understanding hydrologic processes at the watershed scale. In conjunction with looking at the dynamics of water flow, the land use application and soil classification serves as a further indicator suggesting the type of ecological environment and influences the lakes or stream of interest may currently possess. This information is valuable when trying to interpret chemical characteristics and the types of aquatic biota in the lake or stream without having to travel to the area.

4.1 Theory of Measurement

Digital elevation models provide a 3-dimensional representation of a surface terrain and contain values that are horizontally and vertically referenced to a gridded coordinate system based on a datum, geoid (or spheroid) model, and a local projection. NEON utilizes the World Geodetic System 1984 (WGS84) datum, and a local Universal Transverse Mercator (UTM) projection for horizontal reference, and Geoid12A for high-accuracy vertical reference (RD[03]). External data not utilizing the identified datum were converted to WGS84 and re-projected into a local UTM surface projection. For details on NEON's Basic LiDAR Theory for Airborne Laser Mapping see RD[04].

4.2 Theory of Algorithm

This workflow serves the purpose to provide high-resolution watershed boundaries for NEON's aquatic field sites. The Elevation – LiDAR (DP3.30024.001) Level 3 (L3) data product (AD[02]) required to complete the L4 data transformation is a 1 meter resolution Digital Terrain Model (DTM) raster and serves as the high-resolution elevation model from which the watersheds were derived. The DTM can be downloaded from the NEON website data portal https://data.neonscience.org/home. In cases where NEON data did not provide a complete watershed (AD[05]), a 1/3 arc-second (10 meter) resolution Digital Elevation Model (DEM) raster, available from the U.S. Geological Survey (USGS) website (ER[04]), was utilized to provide full coverage of the watershed extent. A mosaic dataset was created to combine individual DTM or DEM tiles, and a local projection defined for the dataset. ArcGIS Pro software with the ArcHydro Tools [for] Pro were used to model and delineate the watershed (ER[03], ER[07]).

A depressionless DEM created from the input mosaic removes erroneous data errors in the DEM creating a smooth elevation surface. By identifying low elevation cells surrounded by higher elevation cells and manipulating the elevation value to eliminate low points (sinks) in the grid, the adjusted DEM is then run through the Basic Dendritic Terrain Processing model to produce drainage basin rasters, catchment areas, and drainage lines.

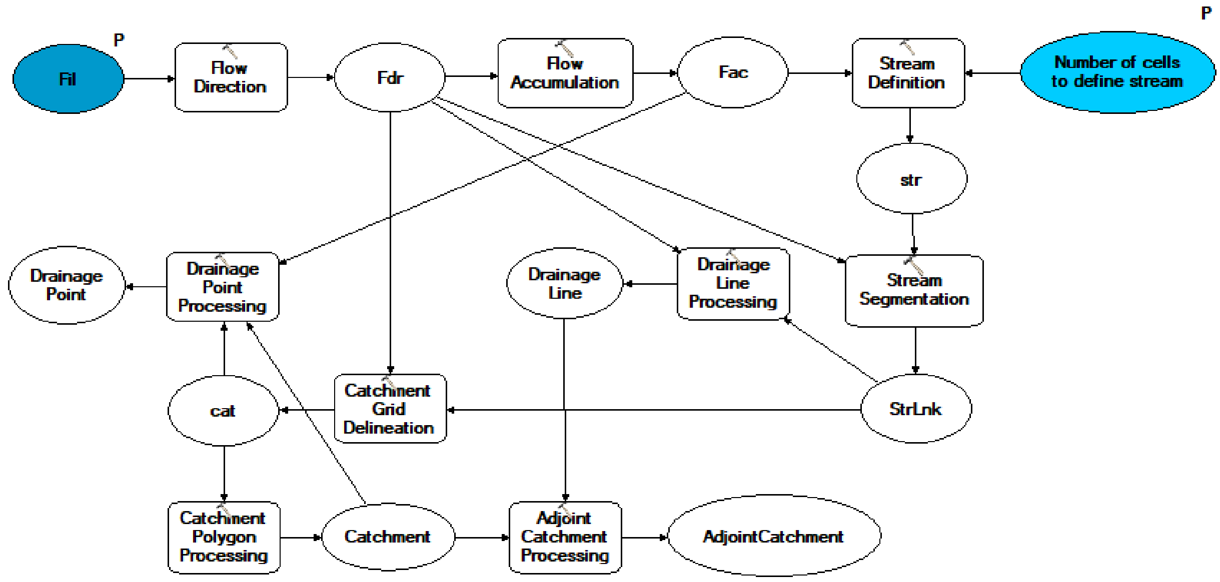

Figure 1. Basic Dendritic Terrain Processing Model

The Basic Dendritic Terrain Processing model is comprised of 9 tools [**Figure 1**].

- Flow Direction generates a raster that identifies the direction of water flow across the landscape based on the direction of the steepest descent in each cell.
- Flow Accumulation generates a weighted raster of cells where the cumulative count of pixels along the defined flow direction is identified for every cell. Areas of high accumulation represent the drainage basin and areas of no accumulation (e.g. zero) represent the watershed boundary.
- Stream Definition is defined through a default threshold of 1% of the maximum flow accumulation. Cells with accumulation greater than 1% are classified as stream cells and all other cells are classified as land surface draining into those streams.
- Stream Segmentation generates a raster grid of unique stream links at every confluence by connecting head segments (the most upstream stream branch) and an outlet, or a junction and the drainage divide.
- Drainage Line Processing converts the stream link grid into a Drainage Line feature class. Each line in the feature class carries a unique identifier of the catchment in which it resides and how it connects to its downstream features. In cases where a line has more than one downstream feature, a Drainage Line Flow Split Table identifies the other, secondary downstream feature(s).
- Catchment Grid Delineation generates the Catchment raster in which each cell carries a value (grid code) indicating to which catchment the cell belongs. The value corresponds to the value of the stream link defined during Stream Segmentation.

- Catchment Polygon Processing converts the Catchment raster into a polygon area feature class.
- Adjoint Catchment Processing generates an Adjoint Catchment polygon feature class representing the aggregated area upstream from the head catchment (identified during the Catchment Grid Delineation) that drains into the inlet point of the Catchment feature class. In cases where a catchment has more than one downstream feature, as identified in the Drainage Line Flow Split Table, an Adjoint Catchment Flow Split Table with a corresponding value is generated to identify the other downstream catchment(s).
- Drainage Point Processing creates a drainage point at the downstream most point in the catchment.

A pour point, representing the downstream most sensor set in the NEON AIS reach, is used to create a local outlet representing the lowest point along the boundary of the local watershed. This is primarily the location of the S2 sensor set in wadeable streams, the S1 sensor set in non-wadeable rivers, and the outlet sensor set in lakes.

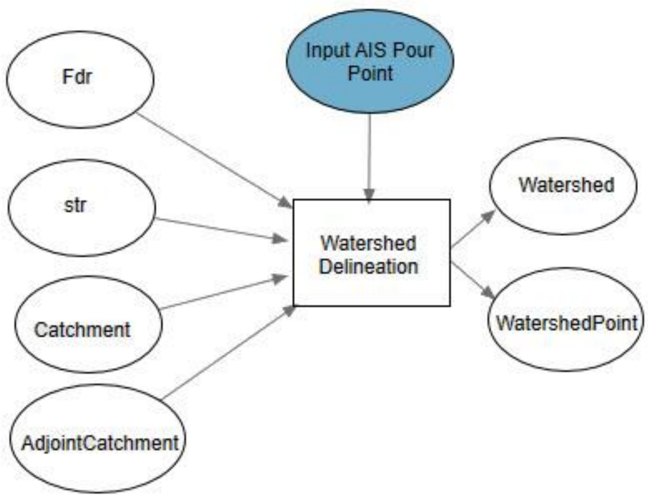

Figure 2. Watershed Delineation Model

The Watershed Delineation script (**Figure 2**) is run with the Flow Direction, Stream, Catchment, and Adjoint Catchment outputs produced from the Basic Dendritic Terrain Processing model to create a polygon area upstream of the defined NEON pour point. The local watershed created from this workflow represents the area of influence where surface water collects and drains into a NEON aquatic field site. A Watershed Point feature class (related to the NEON pour point) is generated with the HydroID of the corresponding Watershed.

Ancillary data within the watershed include thematic land use data classifications from the 2016 (CONUS and AK), and 2001 (PR) National Land Cover Database (NLCD), provided by the Multi-Resolution Land Characteristics (MRLC) Consortium (ER[05]). Soil map unit classifications provided from the Soil Survey

Geographic (SSURGO) database (ER[06]), (available for most sites), and the U.S. General Soil Map (STATSGO) (ER[13]) database (for FLNT, BLWA, TOMB, SYCA, TOOK, OKSR) were collected by the National Cooperative Soil Survey (NCSS), and distributed by the United States Department of Agriculture (USDA), Natural Resources Conservation Service (NRCS). These ancillary data help to identify potential chemical characteristics and provide a general understanding of the surface hydrology and nearby characteristics affecting an aquatic site.

4.3 Special Considerations

There are 11 aquatic sites where NEON's AOP LiDAR did not provide a complete watershed. In these cases a 10 meter National DEM was used to derive the watershed. For 5 of these sites, the watersheds are too large for AOP to complete coverage with the current Operations model. These sites include, D03 Flint River (FLNT), D08 Lower Tombigbee River (TOMB), D10 Arikaree River (ARIK), D11 Blue River (BLUE), and D14 Sycamore Creek (SYCA). Plans are being made for the remaining sites to adjust flight lines and capture the entire extent of the aquatic watershed. In the case of Black Warrior River (BLWA) where AOP coverage is available for the watershed extent, processing errors (possibly due to LiDAR reflectance either reflecting weakly, or being absorbed from water surfaces) generated a high-resolution elevation tile with large gaps in the data. The workflow for this site may be adjust or re-examined to address this issue in the future.

5 ALGORITHM IMPLEMENTATION

Provided is a sequential guide to transform an L3 Data Product into L4 Data for watershed delineation. The land use data and the soils data are secondary applications to show the benefits of overlaying the land use and soils data inside the watershed for additional interpretation.

5.1 Required Platforms, Tools and Inputs

1) ArcGIS Pro 2.4x (ER[07])
   a) Data Management Tools toolbox
      i) Raster tools > Create Raster Dataset
      ii) Raster tools > Add Rasters to Mosaic Dataset
      iii) Feature Class tools > Create Feature Class
   b) Conversion Tools toolbox
      i) To Geodatabase tools > Feature Class to Feature Class
   c) ArcHydro Tools Pro 2.0.47 or later (ER[03])
      i) Terrain Preprocessing toolbox
         (1) DEM Manipulation Tools > Fill Sink
      ii) Terrain Preprocessing Workflows toolbox
         (1) Dendritic tools > Basic Dendritic Terrain Processing
         (2) Watershed Processing tools > Watershed Delineation
2) Elevation Model
   a) Digital Terrain Model
      i) DTM.tif(s) tiles downloaded from the NEON Data Portal, Elevation - LiDAR data product (AD[02])
   b) Digital Elevation Model
      i) DEM.tif(s) downloaded from the USGS National Map Data Download Service (ER[04])
3) NEON AIS Sensors (AD[06])
   a) S2 sensor set in wadeable streams, the S1 sensor set in non-wadeable rivers, and the outlet sensor set in lakes

5.2 Data Processing

Italicized text indicates action

Bold text indicates expression

[Encapsulated] text indicates result

5.2.1 Mosaic

DTM tiles provided by NEON or DEM tiles provided by USGS added to a mosaic dataset and projected in the local UTM zone.

1. *Open* ArcPro 2.4.0 or later
   a. Create new project
      i. New > Map > Create a New Project > Create Name and output Location > Check box for Create a new folder for this project
2. *Create Mosaic Dataset*
   a. View Tab > Catalog View > Navigate to project folder, then to geodatabase > Right click geodatabase > New > Mosaic Dataset
      i. Output Location: **Navigate to work folder File Geodatabase path**
      ii. Mosaic Dataset Name: "**Site_LiDAR" or "Site_NED"**
      iii. Coordinate System: Projected Coordinate System
         1. UTM > WGS 1984 > Northern Hemisphere > WGS 1984 UTM Zone xN
      iv. Product Definition: **None**
      v. Product Properties: **Default**
      vi. Pixel Properties: **Default**
      vii. Run
   b. Result: [Empty Site Mosaic Dataset]
3. Add Rasters To Mosaic Dataset
   a. Data Management Tools > Raster > Mosaic Dataset> Add Rasters to Mosaic Dataset tool
      i. Select Mosaic Dataset created in **5.2.1.2**
      ii. Raster Type: **Raster Dataset**
      iii. Processing Templates: **Default**
      iv. Input Data: **Dataset**
      v. Browse: **Add Elevation (DTM/DEM) .tif files**
      vi. Advanced Input Data Options: **Default**
      vii. Raster Processing:
         1. Check box for Calculate Statistics
         2. Check box to Build Raster Pyramids
         3. Maximum Levels: Default
         4. Maximum Cell Size: Default
      viii. Mosaic Post-processing: **Default**
   b. Result: [Mosaic Dataset of DTM or DEM tiles]

5.2.2 Watershed Delineation

1. Fill Sinks
   a. Arc Hyrdo Tools Pro Toolbox > Terrain Preprocessing > *DEM Manipulation > Fill Sinks*
      i. Input DEM Raster: **Site_LiDAR or Site_NED**

ii. Output Hydro DEM Raster: Navigate to work folder, rename: **Fil**
iii. Fill Threshold (optional): **Leave blank**
iv. Input Deranged Polygon Feature Class (optional): **Leave blank**
v. Use IsSink Field box: **Leave unchecked**

b. Result: [Fil raster]

2. Basic Dendritic Terrain Processing
   a. *Arc Hydro Tools Pro Toolbox > Terrain Preprocessing Workflows > Dendritic > Basic Dendritic Terrain Processing*
      i. Input Hydro DEM raster: **Fil** (created in 5.2.2.1)
      ii. Output Drainage Line Feature Class: Navigate to work folder: **DrainageLine**
      iii. Output Drainage Line Flow Split Table: Navigate to work folder: **DrainageLine_FS**
      iv. Output Catchment Feature Class: Navigate to work folder: **Catchment**
      v. Output Adjoint Catchment Feature Class: Navigate to work folder: **AdjointCatchment**
      vi. Output Catchment Flow Split Table: Navigate to work folder: **Catchment_FS**
      vii. Output Drainage Point Feature Class: Navigate to work folder: **DrainagePoin**t
      viii. Output Flow Accumulation Raster: Navigate to work folder: **fac**
      ix. Output Flow Direction Raster: Navigate to work folder: **fdr**
      x. Output Catchment Raster: Navigate to work folder: **cat**
      xi. Output Stream Link Raster: Navigate to work folder: **StrLnk**
      xii. Output Stream Raster: Navigate to work folder: **str**
   b. Result: [DrainageLine, DrainageLine_FS, Catchment, AdjointCatchment, Catchment_FS, DrainagePoint, fac Raster, fdr Raster, cat Raster, StrLnk Raster, str Raster]

5.2.3 Pour Point

Generate a point using the downstream most AIS sensor set, primarily NEON's S2 sensor in wadeable streams, S1 in non-wadeable rivers, and the outlet sensor in lakes.

1. Create Feature Class
   a. *Data Management Tools Toolbox > Feature Class > Create Feature Class*
      i. Feature Class Location: **Navigate to Work Folder**
      ii. Feature Class Name: **PourPoint**
      iii. Select Geometry Type: **Point**
      iv. Template Feature Class: **Leave blank**
      v. Has M: **No**
      vi. Has Z: **No**
      vii. Feature Class Alias (optional): **Leave blank**
      viii. Environments, Output Coordinate System: **UTM xx**
   b. Result: [Empty PourPoint.shp]
2. Create Pour Point Geometry

   a. *Edit Tab > Create Features Ribbon*
      i. Create Features Templates: **PourPoint**
         1. *Create a pour point on the drainage line nearest the applicable AIS sensor set with left mouse click*
         2. Manage Edits Ribbon > *Save*
      ii. Result: [PourPoint.shp]

5.2.4 Create Watershed

Generate local watershed using inputs from the Basic Dendritic Terrain Processing model and Pour Point.

1. Watershed Delineation
   a. *Arc Hyrdo Tools Pro Toolbox > Watershed Processing > Watershed Delineation*
      i. Input Batch Point Feature Class: **PourPoint** (created in 5.2.3)
      ii. Input Snap Distance: **1**
      iii. Input flow direction raster: **fdr**
      iv. Input Stream Raster: **str**
      v. Input Snap Stream Raster: **str**
      vi. Input Catchment Feature Class: **Catchment**
      vii. Input Adjoint Catchment Feature Class: **AdjointCatchment**
      viii. Input Sink Point Raster: **Leave blank**
      ix. Input Sink Watershed Feature Class: **Leave blank**
   b. Result: [Watershed.shp]
   c. Result: [WatershedPoint]

6 UNCERTAINTY

6.1 Elevation Uncertainty

Watershed delineation was performed at two different spatial scales; the 10 meter resolution (1/3 arc-second) National Elevation Dataset DEM, and the 1 meter resolution.

The 2014 accuracy assessment report from the USGS identifies the absolute vertical uncertainty within the National Elevation Dataset (NED) with a root mean square error of 3.04 meters for the conterminous United States expressed to the 95 percent confidence level in accordance with the National Standard for Spatial Data Accuracy (NSSDA). The accuracy assessment for the 1/3 arc-second NED utilized over 25,000 North America National Geodetic Survey (NGS) benchmarks with millimeter to centimeter-level accuracy (Geoid12A). Root mean square error statistics were produced after bilinear interpolation of the NGS control points and calculated from the residual error of the geodetic control measured against the NED (ER[02]).

Analysis of uncertainty in the NEON Elevation - LiDAR data product is described in AD[04]. Simulated vertical uncertainty associated with each grid cell is reported in a separate raster of uncertainty values as part of the “L3 discrete lidar processing and QA information” packaged with each data product from each site. Simulated uncertainty is obtained from the system errors propagated through to the point cloud, as discussed in RD[04], and then propagated further into the DTM / DSM. Error simulations follow the algorithm described in ER[08] and ER[11], and implement the uncertainty values for each subsystem. Uncertainty in the trajectory can be seen in the associated SBET QAQC document associated with the flight day(s). The range uncertainty is determined from yearly calibration flights at the Boulder airport. Simulated uncertainty is based solely on the instrument sub-systems and does not take into account uncertainty introduced by external surface features or vegetation.

6.2 Model Uncertainty

Within the Basic Dendritic Terrain Processing model, Stream Definition is defined through the use of a default threshold drainage area of 1% of the maximum flow accumulation. Cells in the input flow accumulation grid that have a value greater than the threshold are indicative of the minimum number of cells that characterize a surface drainage. A smaller threshold would result in a denser drainage network (ER[03]).

7 FUTURE PLANS AND MODIFICATIONS

As additional NEON Elevation - LiDAR data become available and the full extent of the site watershed is captured, high-resolution DTM derived watersheds will replace the DEM watersheds derived from the National Elevation Dataset.