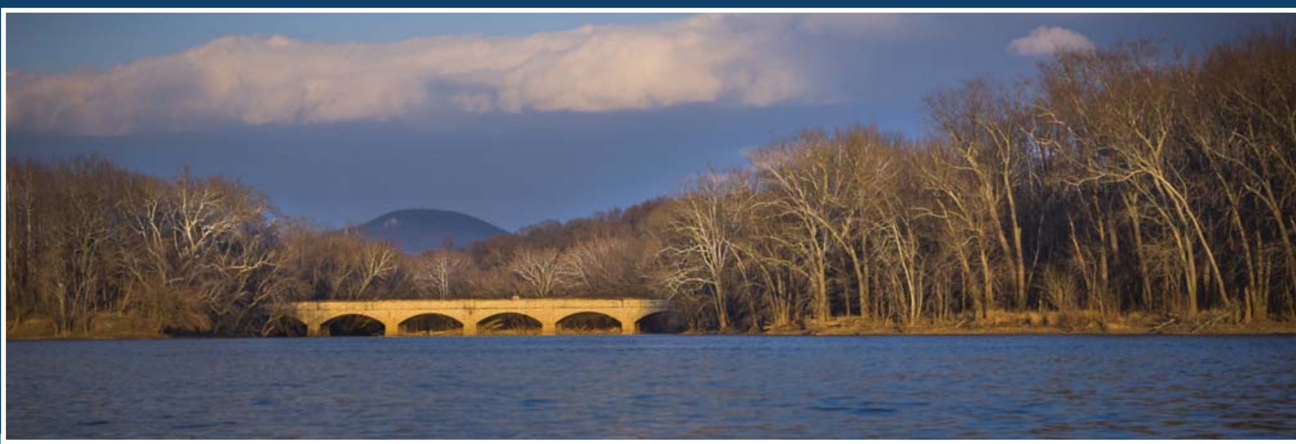
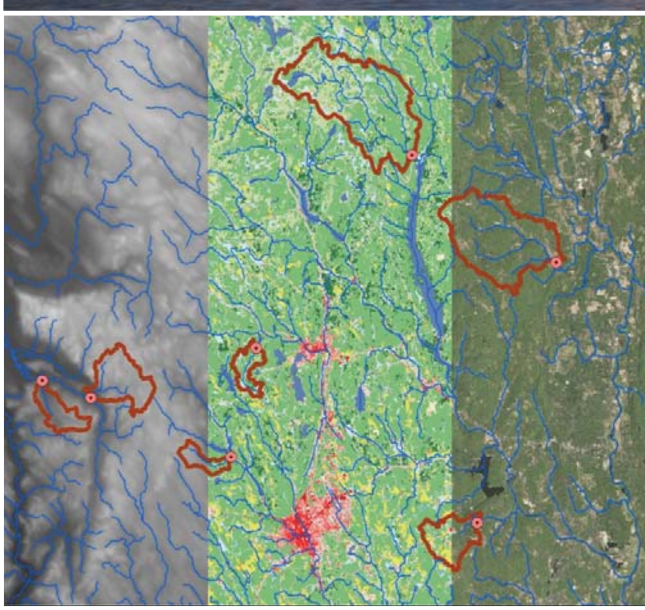
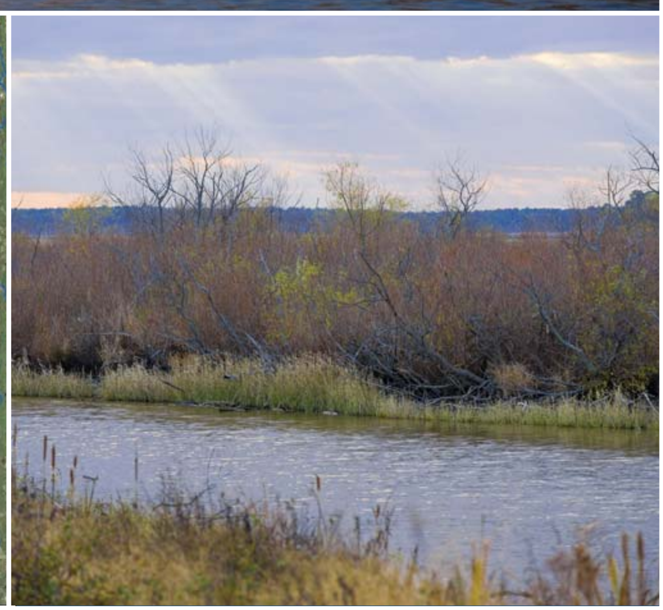
EPA/600/R-17/448F | November 2017 | www.epa.gov/research

United States
Environmental Protection
Agency

Procedures for Delineating and Characterizing Watersheds for Stream and River Monitoring Programs







Office of Research and Development
Washington, D.C.

EPA/600/R-17/448F
November 2017

Procedures for delineating and characterizing watersheds for stream and river monitoring programs

National Center for Environmental Assessment

Office of Research and Development

U.S. Environmental Protection Agency

Washington, DC 20460

Disclaimer

Abstract

Stream and river monitoring organizations often want to know the properties of the watersheds draining to proposed or selected monitoring stations to help select candidate monitoring sites, classify existing sites, or analyze data from existing sites. This manual describes procedures for delineating watersheds at any point on a stream or river, then calculating a suite of watershed characteristics, including land use composition, base flow, channel slope and sinuosity, watershed slope, and enumeration of potential point source facilities of concern. It describes purpose-made ArcMap tools to partially or fully automate all these procedures using the same interface as ArcMap geoprocessing tools. The tools presented in this manual do not exhaustively characterize watersheds but simply cover some basic watershed characteristics in which managers are often interested. If additional watershed characteristics are desired, they can be added after the steps described in this manual. Both the tools and this manual should increase the standardization, efficiency, and reproducibility of watershed characterization within and between monitoring programs. These tools and manual were originally developed for stream Regional Monitoring Networks (RMNs) but can be used for stream or river monitoring programs at spatial scales from municipal to national.

Preferred citation:
Gibbs, DA; Bierwagen, B. (2017) Procedures for delineating and characterizing watersheds for stream and river monitoring programs. (EPA/600/R-17/448F). Washington, DC: U.S. Environmental Protection Agency, Office of Research and Development.

Contents

List of Figures

List of Figures (continued)

List of Abbreviations

CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
DEM	digital elevation model
FID	feature ID
GIS	geographic information system
LUC	land use code
NHD	National Hydrography Dataset
NLCD	National Land Cover Database
NPDES	National Pollutant Discharge Elimination System
RMN	Regional Monitoring Network
USGS	U.S. Geological Survey

Authors and Reviewers

Authors

David A. Gibbs, ORISE fellow, U.S. Environmental Protection Agency, Office of Research and Development

Britta Bierwagen, U.S. Environmental Protection Agency, Office of Research and Development

Reviewers

U.S. EPA Reviewers

Ryan Hill, PhD—ORISE fellow, U.S. Environmental Protection Agency, Office of Research and Development

Phil Morefield, U.S. Environmental Protection Agency, Office of Research and Development

External Peer Reviewers

Timothy Randhir, PhD—Professor, University of Massachusetts, Amherst

Michael Strager, PhD—Professor, University of West Virginia

Dale White, PhD—Water quality engineer, Ohio Environmental Protection Agency

Acknowledgments

We thank the Regional Monitoring Network partners for providing the data used to develop and test these methods.

1. Introduction

Characterizing the properties of contributing watersheds—or the calculation of a suite of properties of the drainage area for a location on a stream—has three main purposes: (1) to screen candidate monitoring sites for some target status (e.g., whether they meet "reference site" status),[1] (2) to classify candidate or actual monitoring sites into various physical stream categories, and (3) to serve as covariates in the analysis of biological community and hydrologic data from monitoring sites.

This manual explains how to use several purpose-made ArcMap tools to calculate watershed properties commonly of interest to resource managers. These include (1) the fraction of land under each National Land Cover Database (NLCD) land use within the whole watershed and within 1- and 5-km radii of the sampling stations within the watershed; (2) the percentage of stream flow that comes from base flow at the sampling station; (3) the channel slope and sinuosity at each station; (4) the slope of the watershed (average, minimum, maximum, range, standard deviation); and (5) the number of dams, mines, National Pollutant Discharge Elimination System (NPDES),[2] and Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)[3] sites within each watershed. The end product is a watershed delineation shapefile that has fields with all of the watershed properties examined. This shapefile can be mapped or exported to other programs for additional analyses, such as the association between macroinvertebrate communities and land use.

Before watersheds can be characterized, they need to be delineated (see Figure 1-1). Delineation is based on the locations of stream sampling or monitoring stations relative to contributing land. Following some preprocessing steps (see Section 2), this manual presents two ways to delineate watersheds (see Section 3); the one that is used depends on the state or territory where the sampling stations are located. Following delineation instructions, the characterization steps are presented (see Section 4). These steps do not produce every characteristic in which resource managers are interested. If further characterization steps are conducted after the steps shown in Figure 1-1, the process can be extended using whatever additional geoprocessing tools are desired. Contact and help information are provided in Section 5. More technical outlines of the characterization tools are provided in Section 6. These methods are an improvement over the previous RMN delineation and characterization methods that approximated characterizations by delineating to the next largest National Hydrography Dataset (NHD) catchment. By only including the area that drains to the sampling stations, rather than "rounding" to the next largest catchment, this method more precisely delineates, and therefore characterizes, watershed properties.

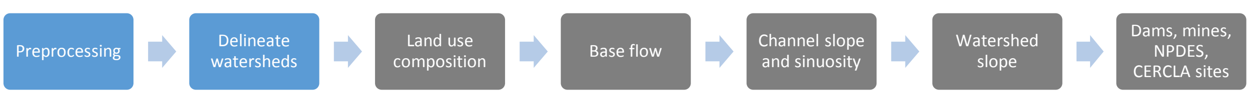


Figure 1-1. Watershed delineation and characterization workflow. Watershed characterization steps are in gray.

[1]"Reference site" can be defined many ways, but, in this context, it refers to the highest quality available sites.
[2]U.S. EPA NPDES homepage: https://www.epa.gov/npdes.
[3]U.S. EPA CERCLA homepage: https://www.epa.gov/superfund/superfund-cercla-overview.

Although this document was written to guide Regional Monitoring Network (RMN)[1] partner agencies (e.g., states, tribes, watershed commissions, EPA regions) in characterizing RMN watersheds, it can also be used by other monitoring programs or groups interested in understanding their own particular watersheds. The slight modifications other programs will need to make to these procedures are not covered in this guide because every program will have its own variation. For example, this guide uses the RMN watershed processing naming system. If this guide is being used for non-RMN programs, the files described below can be renamed accordingly. Furthermore, all sites in the RMNs are designated either primary or secondary sites. Primary sites are core, reference (i.e., least disturbed) sites where all required parameters (biological, physical, habitat, and chemical) are collected. Secondary sites are additional sites of potentially lower quality where fewer parameters are collected. Some states have both primary and secondary sites; some have only primary sites. Both primary and secondary sites in a state can be processed together (in a single file), if desired.

Watersheds in different states should be delineated and characterized (collectively called "processed") separately. There are two main reasons for this. First, the recommended watershed delineation method uses a different projection for geospatial files for every state (see Section 3.1), so each state needs to have a separate sampling station shapefile in the proper projection for delineation. Second, processing states' monitoring stations separately helps with tracking progress and record keeping. This document describes how to delineate and characterize the monitoring stations in one state. If monitoring stations from multiple states are being processed, the directions in this document should be repeated separately for each states' stations.

The directions for running each tool note which ArcMap extensions and/or licenses are required beyond ArcGIS Desktop Basic Version 10.3 or later. Most of the tools described in this guide require the Spatial Analyst extension. One tool requires the 3D Analyst extension and the ArcGIS Desktop Advanced license. The tools have been tested on ArcGIS Desktop 10.3, 10.4, and 10.5. This guide assumes users have basic familiarity with ArcMap.

Links to online help pages are provided for activities or data sets with which users may be less familiar. If the URLs change over time and links break, all of the items can be located through internet searches. Throughout this guide, file names are written in **bold** and parts of file names that are variable are in all capitals inside brackets (e.g., **[STATEABBRV]_landuse_[YYYYMMDD].shp**).

[1]U.S. EPA (2016) Regional monitoring networks (RMNs) to detect changing baselines in freshwater wadeable streams. (EPA/600/R-15/280). Washington, DC: Office of Research and Development, Washington. Available online at https://cfpub.epa.gov/ncea/global/recordisplay.cfm?deid=307973.

2. Preprocessing

Before a watershed can be delineated, some preliminary processing must be done to the sampling stations, which are the basis for watershed delineation and characterization.

1. Sampling stations that are to be characterized must have the following basic information (see Figure 2-1):

   a. Station ID (rename as field "OrgStatnID")

   b. Waterbody name (rename as field "Waterbody")

   c. Responsible agency (rename as field "Entity")

   d. Whether each site is primary, secondary, or under consideration (rename as field "Status")

   e. Additional information (rename as field "Notes")

FID	OrgStatnID	Waterbody	Entity	Status	Notes
202	SF_1	Sipsey Fork	AL DEM	primary	
201	BRSL_3	Brushy Creek	AL DEM	primary	
205	66g_WRD773	Jones Creek	GA DNR	primary	
203	HURR_2	Hurricane Creek	AL DEM	primary	
223	ECO71F29	Hurricane Creek	TN DEC	primary	
219	SV_684	Crane Creek	SC DHEC	primary	
207	66d_44_2	Coleman River	GA DNR	primary	
206	66d_WRD768	Charlies Creek	GA DNR	primary	
204	3890_1	Fightingtown Creek	TVA	primary	

Figure 2-1. Required columns of initial site table.

NOTE: If the stations are in a shapefile (*.shp), proceed to Step 2. If the stations are in another spatial format (e.g., a geodatabase, or in *.kmz format), they must be converted to a shapefile. If they are in a nonspatial format (e.g., Excel spreadsheet), they must have latitudes and longitudes and be imported[1] as a shapefile. Regardless of the route taken, the station shapefile should be named **RMN_primary_secondary_[STATEABBRV].shp**.

NOTE: The shapefile name **RMN_primary_secondary_[STATEABBRV].shp** assumes that both primary and secondary sites are included in the shapefile. If only one type of site is included, change the name of this shapefile and all derivative shapefiles accordingly.

2. Three more fields should be added to **RMN_primary_secondary_[STATEABBRV].shp** and populated (see Figure 2-2):

[1]Importing Excel spreadsheet as shapefile: http://support.esri.com/en/technical-article/000012745.

a. The abbreviation of the state in which the stations are located ("StateAbbrv"; text data type, 10 characters). For sites monitored by non-state organizations, put the state where the site is located, not the name of the monitoring organization.

b. The stations' latitude and longitude ("OrignlLat" [double data type], and "OrignlLong" [double data type], respectively). Latitude and longitude can be populated by right-clicking on the field name ("OrignlLat" and "OrignlLong"), clicking on "Calculate Geometry," and selecting "Latitude" or "Longitude," as appropriate.[1]

FID	OrgStatnID	Waterbody	Entity	Status	Notes	StateAbbrv	OrignlLat	OrignlLong
202	SF_1	Sipsey Fork	AL DEM	primary		AL	34.28558	-87.3991
201	BRSL_3	Brushy Creek	AL DEM	primary		AL	34.3307	-87.2862
205	66g_WRD773	Jones Creek	GA DNR	primary		GA	34.60201	-84.1512
203	HURR_2	Hurricane Creek	AL DEM	primary		AL	34.91799	-86.133
223	ECO71F29	Hurricane Creek	TN DEC	primary		TN	34.91799	-86.133
219	SV_684	Crane Creek	SC DHEC	primary		SC	34.9235	-83.0793
207	66d_44_2	Coleman River	GA DNR	primary		GA	34.95203	-83.5166
206	66d_WRD768	Charlies Creek	GA DNR	primary		GA	34.95895	-83.5716
204	3890_1	Fightingtown Creek	TVA	primary		GA	34.9851	-84.3851

Figure 2-2. Site table with added fields.

3. A text field should be created in **RMN_primary_secondary_[STATEABBRV].shp** called "StationID" (25 characters). This should be populated with the original station IDs ("OrgStatnID"). In "StationID", any station ID more than 25 characters should be shortened to 25 characters or less, and any special characters except underscores (e.g., dash, slash, comma, period) should be replaced with another character. For example, "East Fork First Fork Sinnemahoning Creek" might become "E Fk 1st Fk Sinnemahoning" and "B-099.7" might become "B_099_7". Shortening the station IDs and removing special characters is necessary for using the delineation and characterization tools.

4. Add seven empty fields to **RMN_primary_secondary_[STATEABBRV].shp**.

    a. A text field (200 characters) called "Align_Note".

    b. Two double data type fields called "PourPtLat" and "PourPtLong". These will store the latitude and longitude of the sampling stations once they have been aligned with rasters used for delineation (see Section 3).

    c. A text field (50 characters) called "RMNRegion". This allows sites to be sorted by RMN region once sites from multiple RMN regions are combined after characterization.

    d. A text field (10 characters) called "HUC8". This allows analysis of sites based on the 8-digit hydrologic unit code (HUC8).

[1]Calculate latitude and longitude of points: http://desktop.arcgis.com/en/arcmap/10.3/manage-data/tables/calculating-area-length-and-other-geometric-properties.htm.

e. A long-integer field called "COMID". This field will be used to associate each sampling station with a unique stream reach identifier used in the NHD, which allows RMN sites to be connected to properties calculated for NHD reaches, such as the Index of Watershed Integrity.[1]

f. A double data type field called "Area_km2". This will store the total area of the watershed delineation in square kilometers.

NOTE: Because watershed processing often involves changing stations' IDs and coordinates, the original station IDs and coordinates should be maintained in the station shapefiles in "OrignlLat", "OrignlLong", and "OrgStatnID" fields. Doing so will help match reformatted station names and locations to the original names used in other files.

5. Populate the "RMNRegion" field with the region each station is in. Examples are "Northeast", "Southeast", and "Region 7".

6. Download an HUC8 boundary shapefile or geodatabase for the area covered by **RMN_primary_secondary_[STATEABBRV].shp** from the U.S. Geological Survey (USGS) Watershed Boundary Dataset website[2] and add it into your ArcMap Table of Contents. Populate the "HUC8" field by either manually entering the HUC8 in which each sampling station is located or spatially joining[3] the HUC8 file to the sampling station shapefile and then using "Calculate Attribute" to copy the HUC8 values into the HUC8 field of **RMN_primary_secondary_[STATEABBRV].shp**.

7. Download a shapefile of the EPA Level 3 and Level 4 ecoregions.[4] Spatially join the ecoregions to the sampling stations and delete all fields except "US_L4CODE", "US_L4NAME", "US_L3CODE", "US_L3NAME", "NA_L3CODE", "NA_L3NAME", "NA_L2CODE", "NA_L2NAME", "NA_L1CODE", and "NA_L1NAME" (i.e., delete fields that do not have ecoregion names or codes). No preprocessing is required before the spatial join.

8. Download NHDPlus Version 2 (NHDPlusV2) digital elevation models (DEMs) ("NEDSnapshot.7z") and flowlines ("NHDSnapshot.7z") from the NHDPlusV2 homepage[5] for all land areas likely to be covered by watershed delineations (see Figure 2-3). Some states may have their own high-resolution DEMs, but for consistency among states, the NHDPlusV2 DEMs should be used. NHD flowlines are useful for "ground-truthing" the streams identified during watershed delineation in ArcMap. NHD flowline files will be referred to as **NHDFlowline.shp**. DEMs will be used during both watershed delineation and characterization, so do not delete them until characterization is complete and checked. For large states with monitoring stations spread out over a wide area, it may be necessary to

[1]Index of Watershed Integrity: https://cfpub.epa.gov/si/si_public_record_report.cfm?dirEntryId=309175.
[2]USGS HUC8 files: ftp://rockyftp.cr.usgs.gov/vdelivery/Datasets/Staged/Hydrography/WBD/.
[3]Spatial join: http://pro.arcgis.com/en/pro-app/tool-reference/analysis/spatial-join.htm.
[4]EPA Level 3 and Level 4 Ecoregions:
https://www.epa.gov/eco-research/level-iii-and-iv-ecoregions-continental-united-states.
[5]NHDplusV2 homepage: http://www.horizon-systems.com/NHDPlus/NHDPlusV2_data.php.

download DEMs from several NHD subregions; each region should have just one flowline shapefile.

Preprocessing is now complete and you can delineate the watersheds for these sampling stations.

HTTP Download	FTP Download	File Name
HTTP	FTP	0release_notes_VPU02.pdf
HTTP	FTP	NHDPlusV21_MA_02_02a_CatSeed_01.7z
HTTP	FTP	NHDPlusV21_MA_02_02a_FdrFac_01.7z
HTTP	FTP	NHDPlusV21_MA_02_02a_FdrNull_01.7z
HTTP	FTP	NHDPlusV21_MA_02_02a_FilledAreas_01.7z
HTTP	FTP	NHDPlusV21_MA_02_02a_Hydrodem_01.7z
HTTP	FTP	NHDPlusV21_MA_02_02a_NEDSnapshot_01.7z
HTTP	FTP	NHDPlusV21_MA_02_02b_CatSeed_01.7z
HTTP	FTP	NHDPlusV21_MA_02_02b_FdrFac_01.7z
HTTP	FTP	NHDPlusV21_MA_02_02b_FdrNull_01.7z
HTTP	FTP	NHDPlusV21_MA_02_02b_FilledAreas_01.7z
HTTP	FTP	NHDPlusV21_MA_02_02b_Hydrodem_01.7z
HTTP	FTP	NHDPlusV21_MA_02_02b_NEDSnapshot_01.7z

Figure 2-3. Excerpt of the NHDPlus Version 2 download page for the Mid-Atlantic. Many NHD regions are divided into multiple subregions, which makes file sizes smaller; the Mid-Atlantic has two subregions (a and b). Each subregion has its own DEM file, among other files. The DEMs ("NEDSnapshot") for the Mid-Atlantic region are boxed. Each region has one NHD flowline file called "NHDSnapshot".

3. Watershed delineation

Delineating watersheds is the precursor to characterizing them. This manual describes two watershed delineation methods: (1) the USGS StreamStats[1] web tool and (2) a series of geoprocessing tools in ArcMap. Both methods allow users to delineate watersheds from whatever points on streams they choose (i.e., users are not limited to delineating watersheds in increments of NHD catchments, the nearest USGS gage, etc.). Whenever possible, delineation using the first method (StreamStats) is preferable to delineation using ArcMap's tools because of its simplicity, lower time and technical requirements, and lower risk of delineation errors.

Both methods require aligning sampling stations to flowline rasters, which are the rasterized depictions of the paths along which water accumulates (i.e., where streams and rivers occur according to DEMs). Flowline rasters will generally closely match their corresponding NHD stream flowlines (see Figure 3-1). Aligning sampling stations to flowline rasters tells StreamStats and ArcMap which stream raster cells flow to which sampling stations, allowing the programs to delineate the correct watershed boundaries for the given sampling stations.

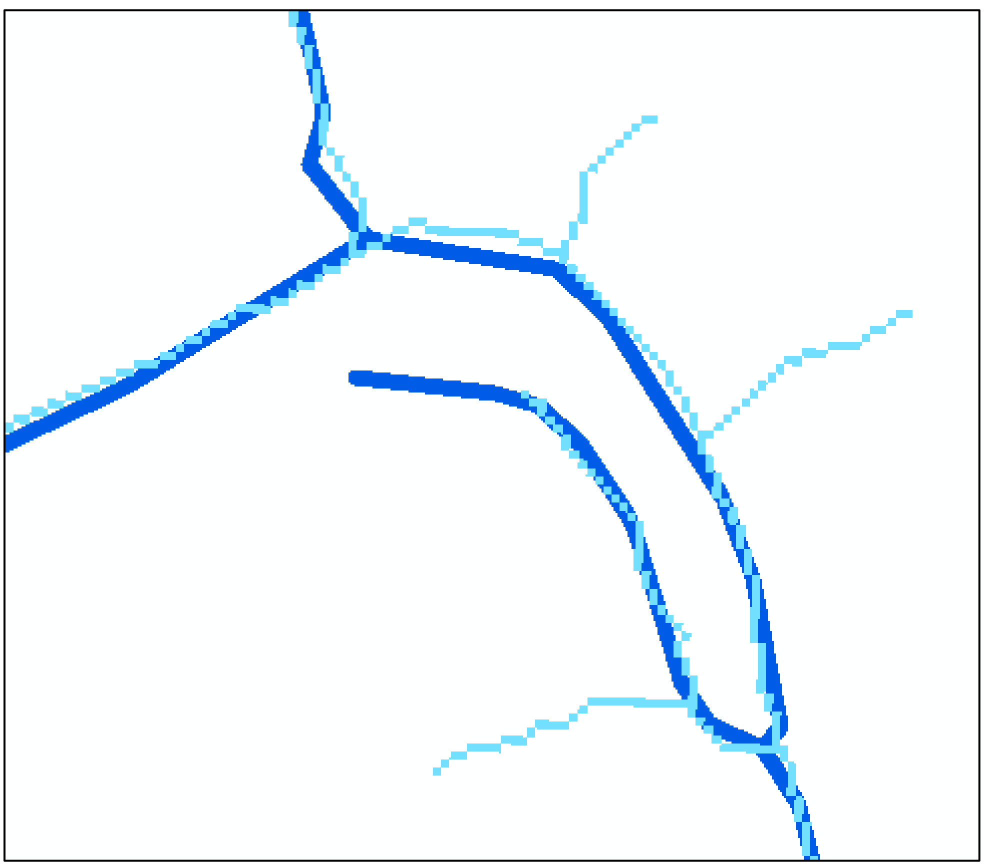


Figure 3-1. StreamStats flowline raster (light blue boxes) and NHD flowline (dark blue lines).

[1]USGS StreamStats home page: https://water.usgs.gov/osw/streamstats/.

3.1. For states with StreamStats batch processor available

StreamStats is an online service that delineates watersheds given one or more points on streams and calculates various hydrologic and drainage area properties. States partner with the USGS to develop a StreamStats application for their state. While most states have fully functional StreamStats applications, a few do not (as of October 2017).[1] For states with functional StreamStats, Version 3 has a batch processing feature to which users can submit a point shapefile and receive a geodatabase containing watershed delineations for those points. Delineation procedures are the same for all states with a StreamStats application.

To use the batch delineation[2] feature of StreamStats, sampling stations must be aligned to StreamStats flowline rasters, the rasterized depiction of where the streams are. (Refer to the StreamStats website for details on how USGS created StreamStats' flowline rasters.) StreamStats flowline rasters do not always match the exact course of rivers and streams but they are generally close; regardless, sampling stations must be aligned to the flowline rasters for delineation to work. Each state with a functioning StreamStats batch processor has its own flowline raster in a state-appropriate projection.

1. Download the StreamStats flowline raster(s) for the state(s) with which you are working.[3]
2. Each state's StreamStats flowline raster is in a different, state-appropriate projection. Because sampling stations must be in the same projection as their state's flowline raster, the sampling station shapefile for each state must be reprojected[4] into the StreamStats raster's projection (see Figure 3-2). The reprojected sampling stations should be named **RMN_primary_secondary_[STATEABBRV]_reproj.shp**. If the sampling stations' shapefiles are not reprojected to the flowline rasters, misalignment of the sampling stations to the flowline rasters and incorrect delineations could occur.

[1]The status of StreamStats state applications is here: http://water.usgs.gov/osw/streamstats/ssonline.html.
[2]USGS StreamStats batch feature: http://streamstatsags.cr.usgs.gov/ss_bp/.
[3]StreamStats flowline raster download: http://streamstatsags.cr.usgs.gov/WebServices/StreamGrids/directoryBrowsing.asp.
[4]Reprojection: http://desktop.arcgis.com/en/arcmap/10.3/tools/data-management-toolbox/project.htm.

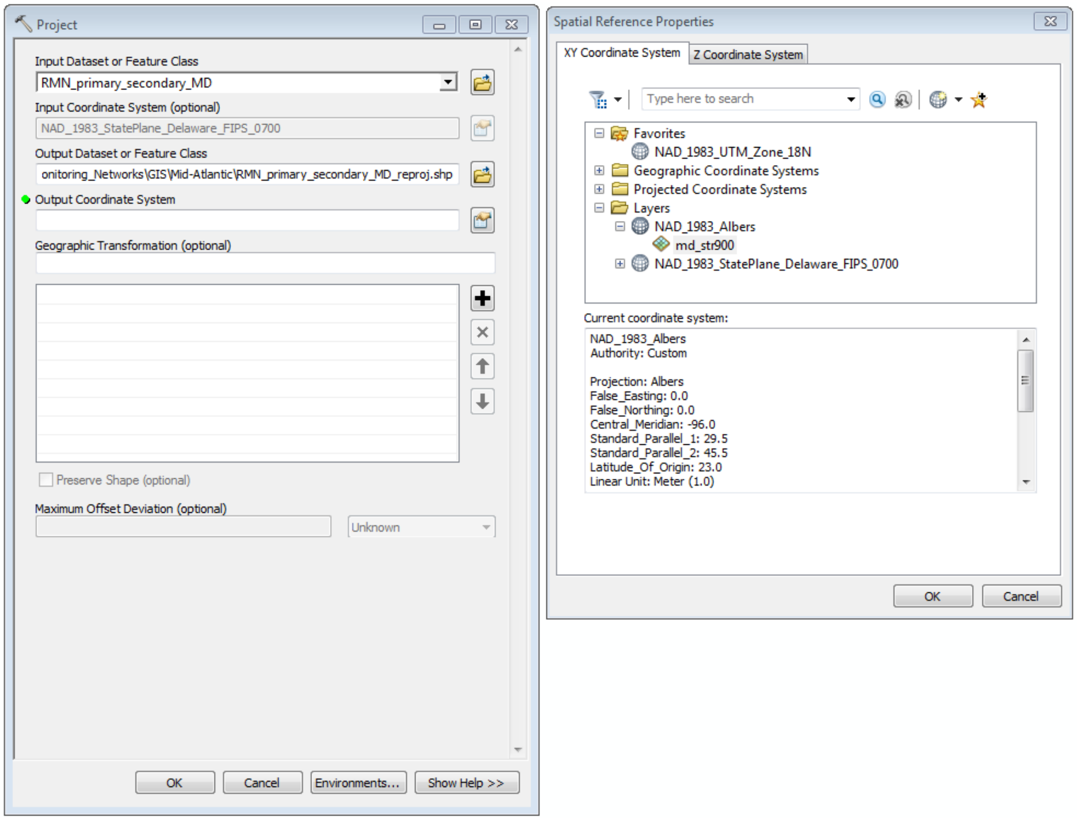


Figure 3-2. Reprojecting sampling stations into projection of StreamStats flowline raster. The desired projection is that of "md_str900".

3. Copy the reprojected sampling station shapefile, naming it **RMN_primary_secondary_[STATEABBRV]_reproj_aligned.shp**. The sampling stations in this shapefile will eventually be aligned to their flowline raster and submitted to StreamStats for delineation.

4. Load **RMN_primary_secondary_[STATEABBRV]_reproj_aligned.shp** and its corresponding flowline raster into ArcMap's Table of Contents. Load the study area's NHD flowlines into the Table of Contents. Add a basemap with aerial imagery for further visualization of rivers and streams, if desired.

5. Enter editor mode[1] and make **RMN_primary_secondary_[STATEABBRV]_reproj_aligned.shp** editable (see Figure 3-3). Zoom to the first station in the attribute table of the shapefile.

[1]Editor mode: http://desktop.arcgis.com/en/arcmap/10.3/manage-data/editing-fundamentals/starting-an-edit-session.htm.

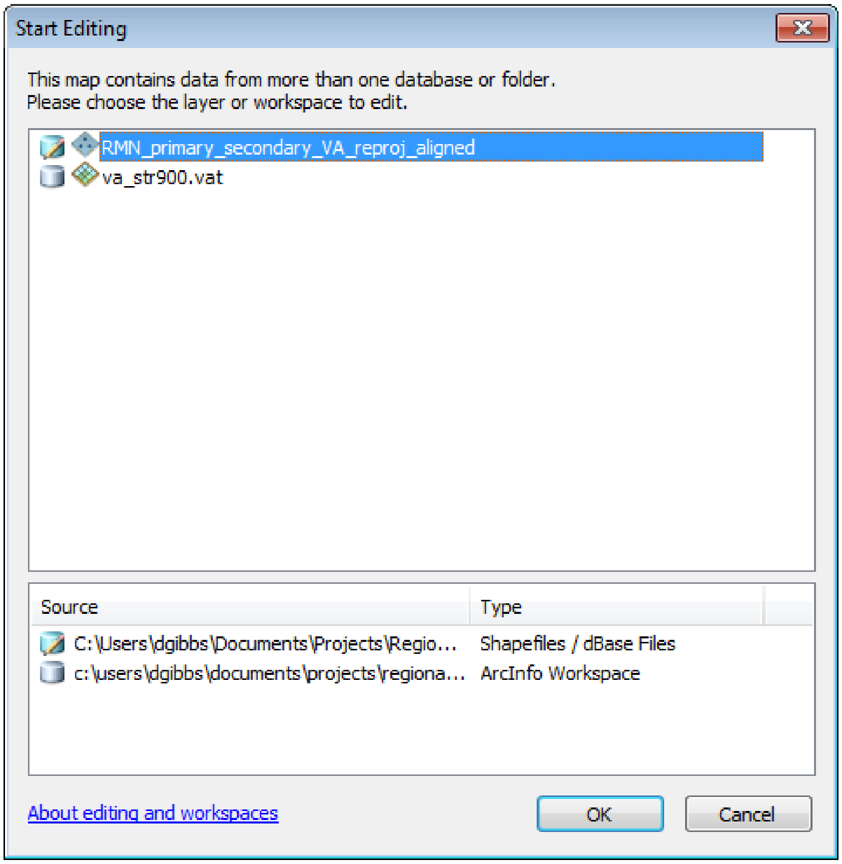


Figure 3-3. Entering editor mode for the sampling station shapefile RMN_primary_secondary_[STATEABBRC]_reproj_aligned.shp. The two files shown in the window are the two files present in ArcMap's Table of Contents.

6. Align each sampling station to the flowline raster by moving the sampling stations to the appropriate pixel of the flowline raster (see Figure 3-4). Sampling stations can be moved[1] by clicking on and dragging them to the desired location. There are four general situations for the alignment of sampling stations to flowline rasters:

    a. A sampling station could be located directly on the flowline raster (see Figure 3-4a). The station does not need to be moved in order to align it with the flowline raster (see Figure 3-4b).

    b. A sampling station could be located off of the flowline raster but in a location where it is easy to tell where it should be on the flowline raster to within a few pixels (see Figure 3-4c). The station should be moved to a plausible flowline raster pixel (see Figure 3-4d). Do not worry about aligning to the exact stream pixel that corresponds with where sampling occurs.

[1]Moving features: http://webhelp.esri.com/arcgisdesktop/9.3/index.cfm?TopicName=Moving_features.

c. A sampling station could be at the confluence of multiple flowlines and it is not clear whether it is on one of the branches or downstream of the confluence (see Figure 3-4e). Clarification about the location of the station should be sought from site information databases, if available (e.g., USGS site inventory website[1]), or from the source agency, and the station moved accordingly (see Figure 3-4f). Whether the station is on one of the branches or below the confluence can dramatically affect the watershed's boundary.

d. A sampling station is not clearly near any flowline raster. Check the NHD flowlines in the area to see if NHD shows any rivers or streams nearby. Clarification about the location of the station should be sought from the source agency and the station moved accordingly. It may be that the coordinates provided by the source are incorrect or that the watershed is very small (less than 900 pixels, or 810,000 m^2 when each pixel is 30 × 30 m). If the latter, you can manually delineate using the DEM and NHD flowlines.

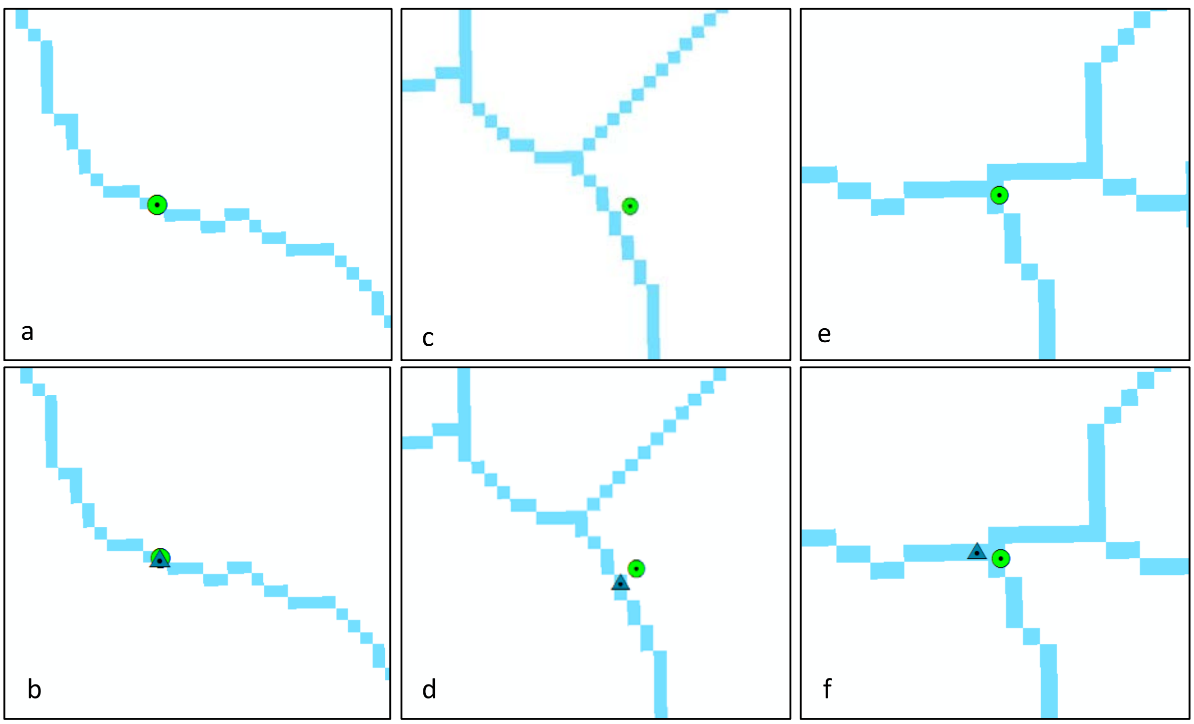


Figure 3-4. Three cases of sampling station-flowline raster alignment. Green circle is the sampling location as provided by the source agency. Purple triangle is the aligned location. In (a), the station is already on the flowline raster (b). In (c), the station is very close to the flowline raster and can be aligned with the flowline raster without additional information (d). In (e), the station is at a confluence and additional information is needed to determine whether sampling occurs on one of the branches or below the confluence (f).

[1]USGS site inventory: https://waterdata.usgs.gov/nwis/inventory.

7. Any steps needed to align each station with its flowline raster should be noted in the "Align_Note" field of the attribute table of **RMN_primary_secondary_[STATEABBRV[_reproj_aligned.shp** (see Figure 3-5), especially if the location of the sampling station relative to the flowline raster needs clarification from the source agency. Include the name of the database or person that clarified the location of the sampling station and the date it was clarified. Frequently save[1] your edits (changes to point locations and new text in "Align_Note" field).

Align_Note	PourPtLat	PourPtLong	OrignlLat	OrignlLong
Moved	41.474768	-71.834226	41.47482	-71.83424
Moved	41.926721	-73.279898	41.9267	-73.2799
Moved	41.946412	-72.839627	41.946389	-72.839167
Didn't need to move	42.035622	-72.938397	42.035622	-72.938397
Confluence. Meghan Lally (3/16/16	41.410127	-72.329138	41.410047	-72.328939
Moved	41.460296	-72.334188	41.460308	-72.334289
Meghan Lally (3/17/16) said they	41.940829	-72.833893	41.946389	-72.839167

Figure 3-5. Attribute table with alignment notes, original pour point locations, and aligned pour point locations.

8. Add **NHDFlowline.shp** from the NHDPlus download to the Table of Contents. Zoom to the first station in the **RMN_primary_secondary_[STATEABBRV[_reproj_aligned.shp** attribute table. Fill in the "COMID" field for each station based on the nearest NHD COMID.

9. Save your edits again and quit editor mode, then use the "Calculate Geometry"[2] option for fields in the attribute table to populate the "PourPtLat" and "PourPtLong" fields with the latitudes and longitudes of the sampling stations (now the pour points for the watersheds) (see Figure 3-6). At this point, the station shapefile will have four populated coordinate fields: "OrignlLat", "OrignlLong", "PourPtLat" and "PourPtLong" (see Figure 3-5).

---

[1]Saving edits: http://desktop.arcgis.com/en/arcmap/10.3/manage-data/editing-fundamentals/stopping-an-edit-session-stopping-editing-.htm.

[2]Calculating feature geometry: http://desktop.arcgis.com/en/arcmap/10.3/manage-data/tables/calculating-area-length-and-other-geometric-properties.htm.

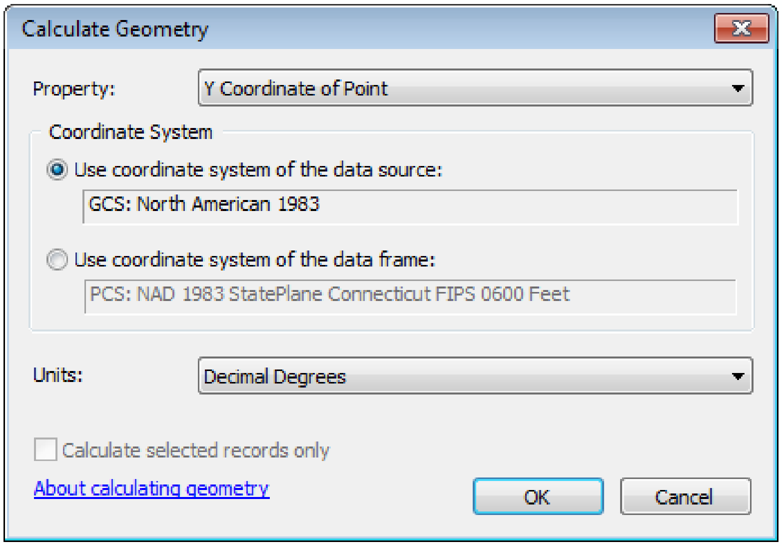


Figure 3-6. Populating the latitude field of a point shapefile's attribute table. Repeat for the longitude field.

10. Once all stations in a state have been aligned with the StreamStats flowline raster, that state's stations can be submitted to the StreamStats batch processor (see Figure 3-7). StreamStats' "Local ID Field" should be the shapefile's "StationID". Depending on your objective, it is not necessary to have StreamStats compute any basin characteristics or flow statistics because each state's applications calculate different parameters, and therefore, the StreamStats-generated statistics are not comparable across states.

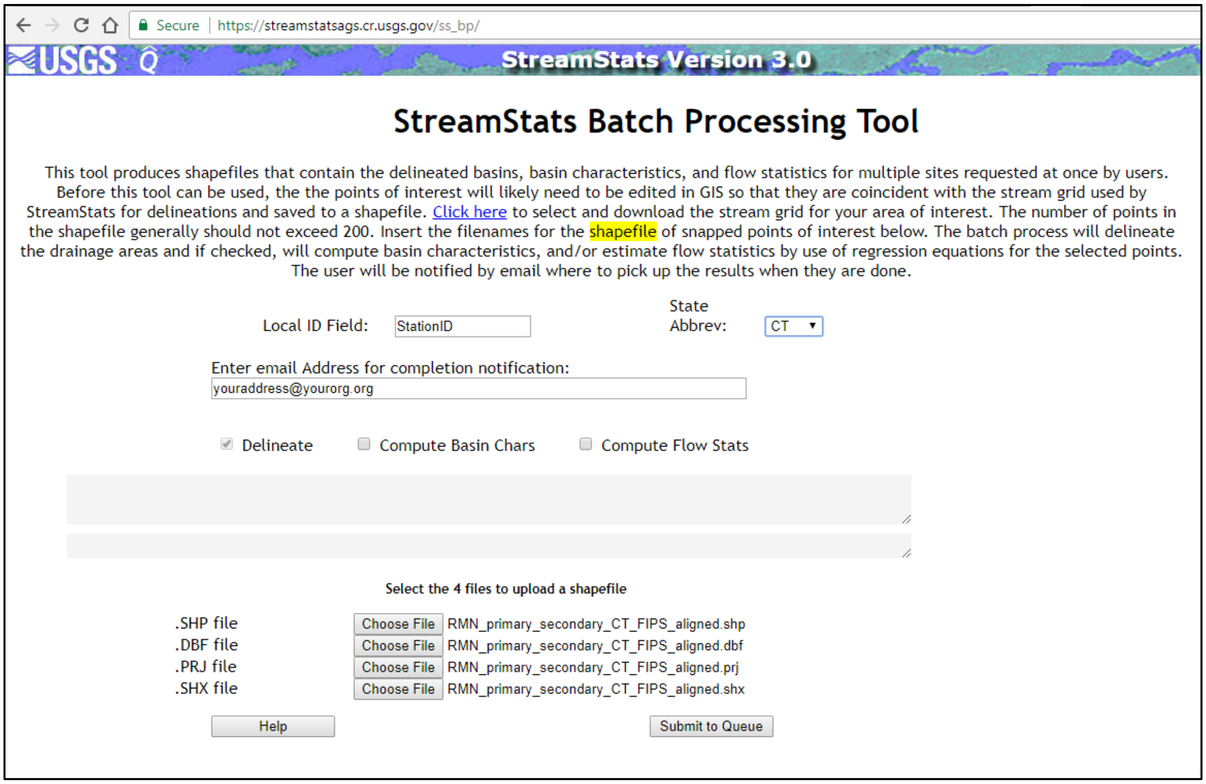


Figure 3-7. StreamStats batch processor upload interface.

11. Up to several hours after the request is submitted, StreamStats will send an e-mail with a link to a database that contains the delineation feature class. Download the database to the appropriate directory on your computer. The relevant feature class is called **GlobalWatershed[STATEABBREV]**. Open this in ArcMap and confirm the following: (1) the number of watersheds in the output files equals the number of stations submitted to StreamStats, (2) the watershed boundaries visually make sense when overlaid with the StreamStats flowline raster (see **Error! Reference source not found.**), and (3) sampling stations near confluences include only the desired stream reach(es). Two common reasons for watersheds missing from the StreamStats feature class are that some StationIDs in the sampling station shapefile include special characters other than underscores, and that the stations are not coincident with the StreamStats flowline raster.

12. Table join[1] the sampling station shapefile to the delineation feature class using the "StationID" and "Name" fields, respectively. ("Name" is what StreamStats uses as the unique ID field; its entries should be the same as the "StationID" entries in the sampling station shapefile.) Export the joined station-delineation feature class to a new shapefile. This will permanently associate the delineations with their sampling stations' attributes.

[1]Table join: http://desktop.arcgis.com/en/arcmap/10.3/manage-data/tables/joining-attributes-in-one-table-to-another.htm.

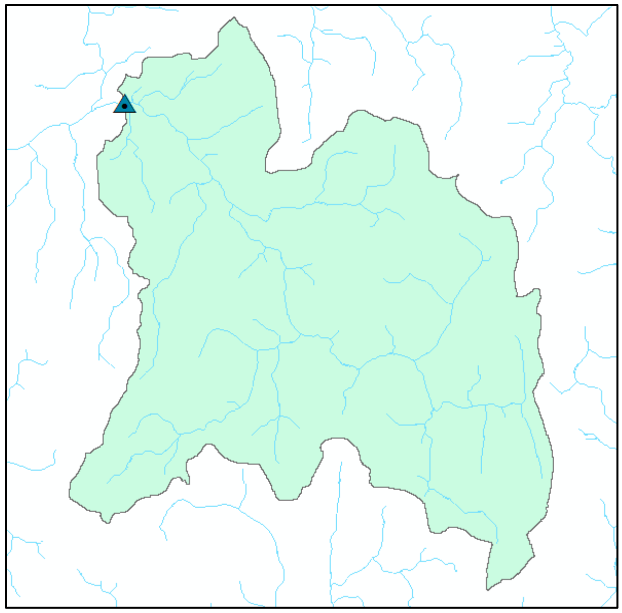


Figure 3-8. Sample StreamStats watershed delineation with StreamStats flowline raster. Sampling station is the purple triangle.

13. Use “Calculate Geometry” on the field “Area_km2” to populate the field with the area of each watershed in square kilometers in the new shapefile.
14. Although having a single DEM for all the RMN watersheds in each state is not part of watershed delineation, it is necessary for every state during watershed characterization and is best done at this point. To get a single DEM that covers all the RMN watersheds in a state, load the delineation shapefile (see Step 12) and the NHD DEMs that are necessary to cover the watersheds into the Table of Contents. Merge them using the “Mosaic to New Raster” tool (see Figure 3-9). “Number of Bands” should equal 1 and “Pixel Type” equal “32_BIT_FLOAT”. Running this for large NHD subregions can take several hours.

At this point, that state’s delineations are completed and watershed characterization can begin.

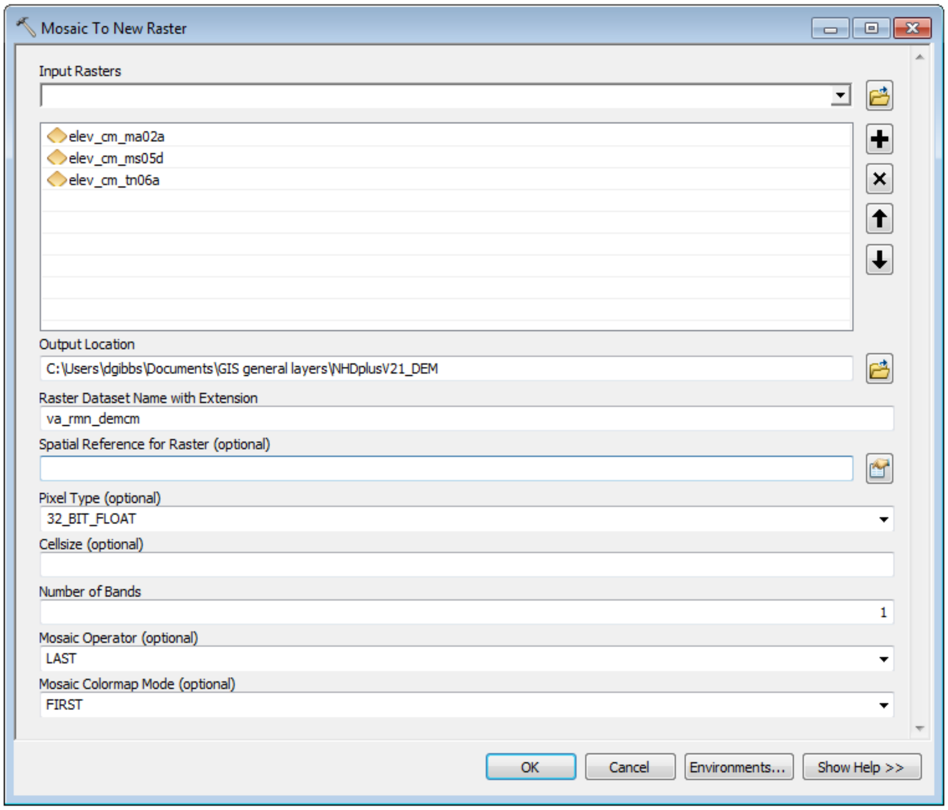


Figure 3-9. "Mosaic to New Raster" configuration for multiple DEMs in the same study area.

3.2. For states without StreamStats batch processor available

For stations in states that do not have the StreamStats batch processor, watersheds can be delineated using a series of geoprocessing tools in ArcMap. The methods below are essentially those found on many websites (e.g., Tufts University[1] and Trent University[2] sites), but modified slightly for RMNs. They deviate most from typical delineation procedures when any watersheds being delineated are nested within others being delineated.

1. Activate the Spatial Analyst and 3D Analyst extensions in ArcMap under Customize > Extensions and check Spatial Analyst and 3D Analyst. You will need these extensions for watershed delineation without StreamStats.

2. It is necessary to have one DEM that covers the entire area covered by the watershed delineations. If multiple subregions of NHD DEMs are necessary to fully cover the areas that will be in the delineations, merge them using the "Mosaic to New Raster" tool[3] (see Figure 3-9). "Number of Bands" should equal 1 and "Pixel Type" should equal "32_BIT_FLOAT".

[1]http://sites.tufts.edu/gis/files/2013/11/Watershed-and-Drainage-Delineation-by-Pour-Point.pdf.
[2]http://www.trentu.ca/library/sites/default/files/documents/WatershedDelineation_10_2.pdf.
[3]Mosaic to new raster:
http://desktop.arcgis.com/en/arcmap/10.3/tools/data-management-toolbox/mosaic-to-new-raster.htm.

Running this tool for large NHD subregions can take several hours. Because the extent of the watersheds is not yet known, deciding which DEM subregions to include involves some guesswork.

3. Use the "Flow Direction" tool[1] on the DEM covering the study area to create a raster showing which direction water flows at each pixel.

4. Use the "Sink" tool[2] to identify sinks in the flow direction raster covering the study area. Sinks are cells that have lower elevation than all surrounding cells; water cannot flow outward from such cells and they cause erroneous delineations. NHD DEMs should not have any sinks in them; sinks will already have been "filled" before the DEMs were posted. If no sinks are identified in this step, skip to Step 7.

5. If Step 4 identified any sinks, use the "Fill" tool[3] on the DEM covering the study area to remove sinks in the study area. This tool may take a lot of time and memory to run.

6. If the study area DEM had any sinks and had to be filled, use the "Flow Direction" tool (see Step 3) on the filled DEM (see Step 5) to get a corrected flow direction raster.

7. Use the "Flow Accumulation" tool[4] on the flow direction raster (from Step 3, if no DEM filling necessary; from Step 6, if DEM filling necessary) to create a raster called **[STATEABBRV]_fill_accum** showing how many pixels drain to each downslope pixel in the study area.

8. Export the flow accumulation raster **[STATEABBRV]_fill_accum** to a TIF with "32_BIT_SIGNED" pixels called **[STATEABBRV]_fill_accum.tif** (see Figure 3-10).

[1]Flow direction: http://pro.arcgis.com/en/pro-app/tool-reference/spatial-analyst/flow-direction.htm.
[2]Sink: http://pro.arcgis.com/en/pro-app/tool-reference/spatial-analyst/sink.htm.
[3]Fill: http://desktop.arcgis.com/en/arcmap/10.3/tools/spatial-analyst-toolbox/fill.htm.
[4]Flow accumulation: http://pro.arcgis.com/en/pro-app/tool-reference/spatial-analyst/flow-accumulation.htm.

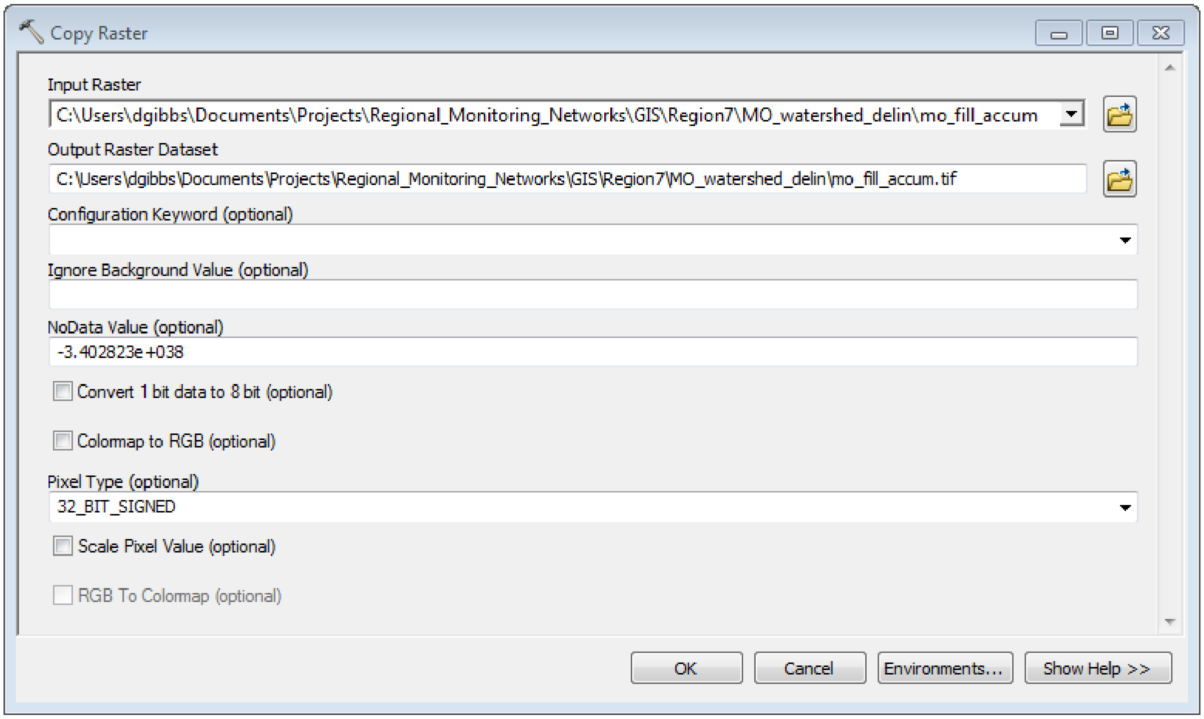


Figure 3-10. Exporting flow accumulation raster to 32-bit signed TIF.

9. Use the "Build Raster Attribute Table" tool[1] to create an attribute table for the TIF flow accumulation raster **[STATEABBRV]_fill_accum.tif** (see Figure 3-11).

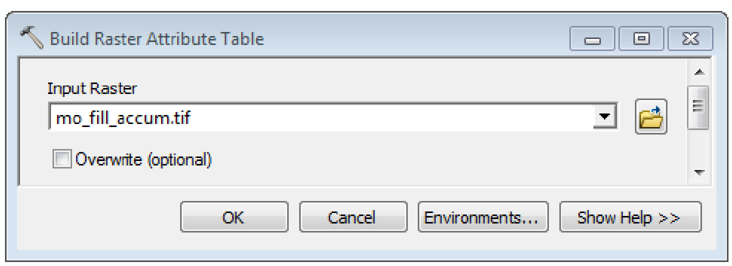


Figure 3-11. Creating an attribute table for the flow accumulation raster.

10. Use the "Extract by Attributes" tool[2] (Spatial Analyst extension required) to convert the flow accumulation raster into a flowline raster. Inputting 900 for the "Where clause" field will produce a raster in which the flowlines drain more than 900 pixels (810,000 m^2 for 30 × 30 m pixels) and generally provides well-defined flowline rasters for headwaters (see Figure 3-12). Flowline rasters with a minimum drainage area of 900 DEM pixels results

[1]Build raster attribute table: http://desktop.arcgis.com/en/arcmap/10.3/tools/data-management-toolbox/build-raster-attribute-table.htm.
[2]Extract by attributes: http://pro.arcgis.com/en/pro-app/tool-reference/spatial-analyst/extract-by-attributes.htm.

in a reasonable number of streams for these purposes. Change the color of the flowline raster to blue. This flowline raster is a rough, less processed version of the flowline raster downloaded from StreamStats. The flowline raster should approximate the NHD flowlines.

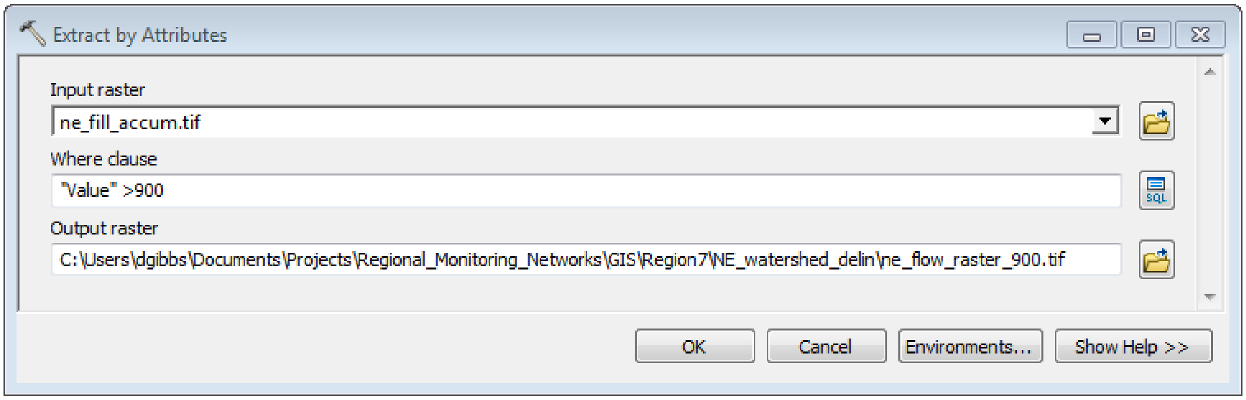


Figure 3-12. Converting the flow accumulation raster into a flowline raster.

11. Reproject[1] **RMN_primary_secondary_[STATEABBRV].shp** to the projection of the DEM/flow accumulation grid, naming it **RMN_primary_secondary_[STATEABBRV]_reproj.shp**. Not reprojecting the sampling station shapefiles to the projection of the flowline rasters could lead to misalignment of the sampling stations to the raster and incorrect watershed delineations.

12. Copy the reprojected sampling station shapefile from Step 11, naming it **RMN_primary_secondary_[STATEABBRV]_reproj_aligned.shp**. The sampling stations in this shapefile will be aligned to their flowline raster (from Step 9) for delineation. Load the study area's NHD flowlines into the Table of Contents. Add a basemap with aerial imagery for further visualization of rivers and streams, if desired.

13. Enter editor mode[2] and make **RMN_primary_secondary_[STATEABBRV]_reproj_aligned.shp** editable (see Figure 3-3). Zoom to the first station in the shapefile.

14. Align each sampling station to the flowline raster by moving the sampling stations to the appropriate pixel of the flowline raster (see Figure 3-4). Sampling stations can be moved[3] by clicking on and dragging them to the desired location. There are four general situations for the alignment of sampling stations to flowline rasters:

[1]Reproject: http://desktop.arcgis.com/en/arcmap/10.3/tools/data-management-toolbox/project.htm.
[2]Enter editor mode: http://desktop.arcgis.com/en/arcmap/10.3/manage-data/editing-fundamentals/starting-an-edit-session.htm.
[3]Moving features: http://webhelp.esri.com/arcgisdesktop/9.3/index.cfm?TopicName=Moving_features.

a. A sampling station could be located directly on the flowline raster (see Figure 3-4a). The station does not need to be moved in order to align it with the flowline raster (see Figure 3-4b).

b. A sampling station could be located off of the flowline raster but in a location where it is easy to tell where it should be on the flowline raster to within a few pixels (see Figure 3-4c). The station should be moved to a plausible flowline raster pixel (see Figure 3-4d). Do not worry about aligning to the exact stream pixel that corresponds with where sampling occurs.

c. A sampling station could be at the confluence of multiple flowlines and it is not clear whether it is on one of the branches or downstream of the confluence (see Figure 3-4e). Clarification about the location of the station should be sought from site information databases, if available (e.g., USGS site inventory website[1]), or from the source agency, and the station moved accordingly (see Figure 3-4f). Whether the station is on one of the branches or below the confluence can dramatically affect the watershed's boundary.

d. A sampling station is not clearly near any flowline raster. Check the NHD flowlines in the area to see if NHD shows any rivers or streams nearby. Clarification about the location of the station should be sought from the source agency and the station moved accordingly. It may be that the coordinates provided by the source are incorrect or that the watershed is very small (less than 900 pixels, or 810,000 m^2 when each pixel is 30 × 30 m). If the latter, you can either manually delineate using the DEM and NHD flowlines or repeat Steps 10−13 using a smaller watershed threshold size (e.g., 450 pixels).

15. Any steps needed to align each station with its flowline raster should be noted in the "Align_Note" field of the attribute table of **RMN_primary_secondary_[STATEABBRV[_reproj_aligned.shp** (see Figure 3-5), especially if the location of the sampling station relative to the flowline raster needs clarification. Include the name of the database or person that clarified the location of the sampling station and the date it was clarified. Frequently save[2] your edits (changes to point locations and new text in "Align_Note" field).

16. Add **NHDFlowline.shp** from the NHDPlus download to the Table of Contents. Zoom to the first station in the **RMN_primary_secondary_[STATEABBRV[_reproj_aligned.shp** attribute table. Fill in the "COMID" field for each station based on the nearest NHD COMID.

[1]USGS site inventory: https://waterdata.usgs.gov/nwis/inventory.
[2]Saving edits: http://desktop.arcgis.com/en/arcmap/10.3/manage-data/editing-fundamentals/stopping-an-edit-session-stopping-editing-.htm.

17. Save your edits again and quit editor mode, then use the "Calculate Geometry"[1] option for fields in the attribute table to populate the "PourPtLat" and "PourPtLong" fields with the latitudes and longitudes of the sampling stations (now the pour points for the watersheds) (see Figure 3-6). At this point, the station shapefile will have four populated coordinate fields: "OrignlLat," "OrignlLong," "PourPtLat," and "PourPtLong" (see Figure 3-5).

At this point, the sampling stations have been aligned to flowlines and everything is prepared for delineating the watersheds. The procedures take two routes here, depending on whether any sampling stations are nested inside each other. Nesting occurs when one RMN sampling station is upstream of another one (see a), as opposed to independent branches (see b). Nested sampling stations produce nested watersheds. Delineation is simpler if no watersheds are nested. You can map the sampling station shapefile against the flowline raster to check for nested sampling stations.

[1]Calculating feature geometry:
http://desktop.arcgis.com/en/arcmap/10.3/manage-data/tables/calculating-area-length-and-other-geometric-properties.htm.

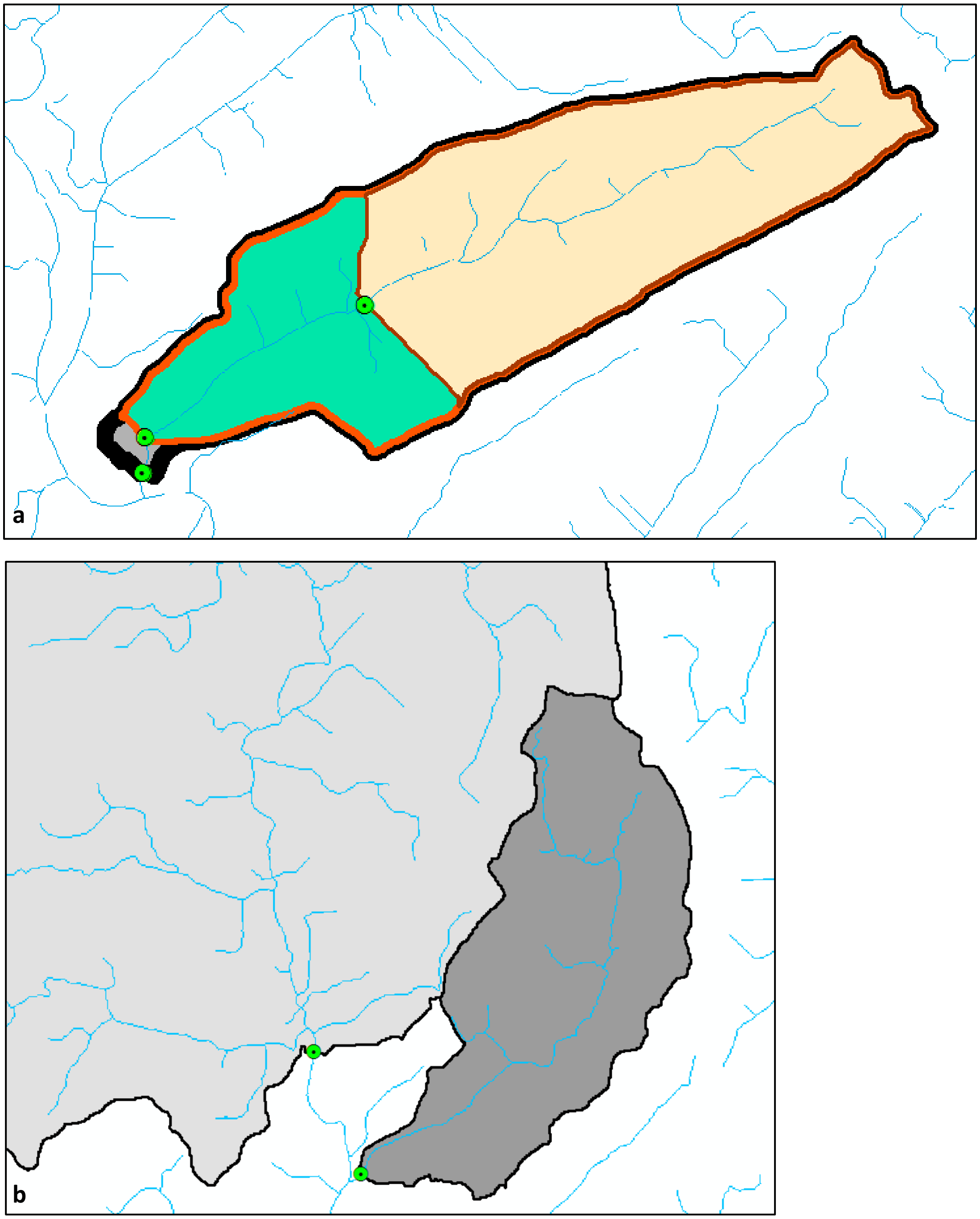


Figure 3-13. Examples of nested and unnested watersheds. Green circles are sampling stations and blue lines are flowline rasters. (a) Example of triply nested watersheds. The watershed outlined in black is the outermost, the watershed outlined in red is the middle level, and the watershed outlined in brown is the innermost. (b) Example of two non-nested, adjacent watersheds (light and dark gray polygons).

If no watersheds are nested:

18. Use the "Watershed" tool[1] on the filled flow direction raster and the aligned pour point shapefile to delineate watersheds. For the "Pour point field", select "FID" (see Figure 3-14) (the "feature ID", an auto-assigned unique identifier for each feature). This will produce a raster in which each pixel found to be in a watershed has the same value as the FID. Each watershed will have a different value pixel according to its pour point FID.

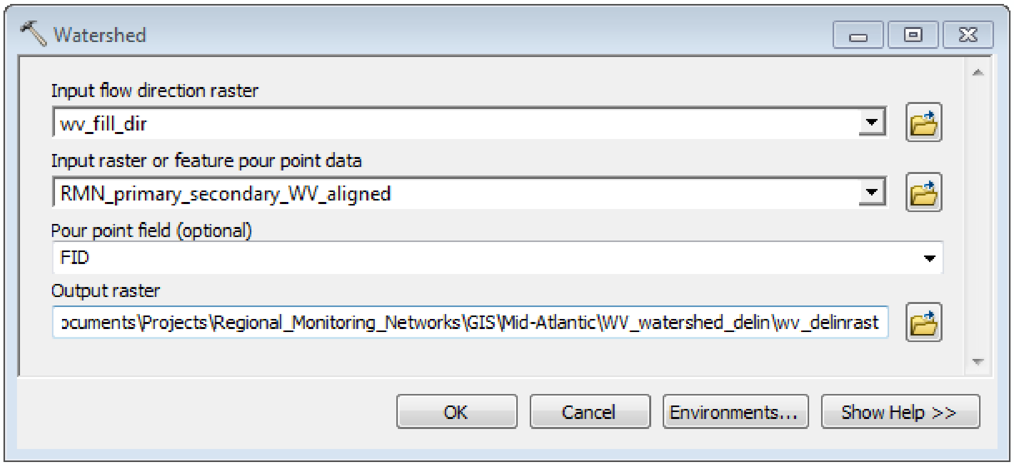


Figure 3-14. Interface for the ArcMap "Watershed" tool.

19. Check that each sampling station has a corresponding watershed delineation raster. A sampling station missing a delineation raster may not have been properly aligned to its flowline raster.

20. Use the "Raster to Polygon" tool[2] on the watershed delineation raster (see Step 19) to convert the delineation raster to delineation polygons. Use the "Simplify" option. This tool will output a polygon shapefile in which each feature is one watershed boundary.

21. Table join the aligned sampling station shapefile to the delineation polygon shapefile using the "FID" field in the station shapefile and the "GRIDCODE" field in the polygon shapefile.

22. Export[3] the joined station-delineation shapefile to a new shapefile. This will permanently associate the delineations with their sampling stations' attributes. This shapefile will be used for watershed characterization. Check the delineation polygons against the flowline raster (see Figure 3-15), NHD flowlines, and DEM to make sure they make sense. Correct the

[1]Watershed delineation: http://pro.arcgis.com/en/pro-app/tool-reference/spatial-analyst/watershed.htm.
[2]Raster to polygon: http://pro.arcgis.com/en/pro-app/tool-reference/conversion/raster-to-polygon.htm.
[3]Exporting a shapefile to a new shapefile: http://support.esri.com/en/technical-article/000004655.

delineation boundaries as needed in an edit session. For example, add[1] and move[2] delineation vertices to extend the boundary around the outsides of the flowlines, tracing along an estimated drainage divide using a DEM for support.

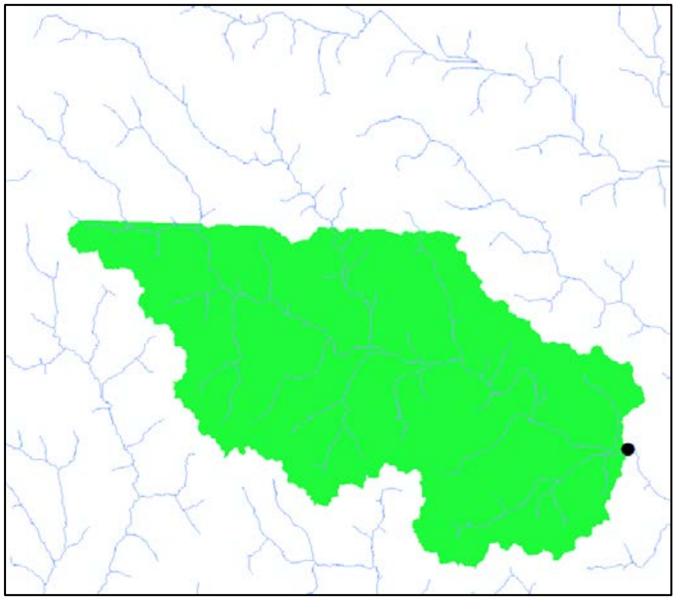


Figure 3-15. Incorrect watershed delineation by Watershed tool in ArcMap. The delineation raster (green) does not extend to the northern ends of the flowline raster (blue lines). The sampling station is black circle.

23. Use "Calculate Geometry" on the field "Area_km2" to populate the field with the area of each watershed in square kilometers in the new shapefile.

This concludes the procedures for delineating non-nested watersheds using ArcMap. Watershed characterization can begin (see Section 4).

Nested sampling stations make the "Watershed" tool produce erroneous results because each pixel output from the "Watershed" tool can only be assigned one watershed value and nested sampling stations, by definition, have more than one watershed value at each pixel within the inner watershed. *Thus, nested sampling stations cannot be delineated during the same run of the "Watershed" tool*; they must be delineated with separate runs of the "Watershed" tool to get complete delineations of each nested watershed. The process below essentially delineates every watershed separately (regardless of whether or not it is nested), then converts each one to a watershed polygon and merges all those polygons into one shapefile.

[1]Add vertices in edit mode: http://desktop.arcgis.com/en/arcmap/10.3/manage-data/editing-existing-features/adding-a-vertex-manually.htm.
[2]Move vertices in edit mode: http://desktop.arcgis.com/en/arcmap/10.3/manage-data/editing-existing-features/moving-a-vertex-by-dragging-it.htm.

If any watersheds are nested:

18. Use the Model Builder tool called **Watershed_delin_by_each_feature_20160824** to get a separate delineation raster for each sampling station with each station's FID at the end of its name. Check that each sampling station has a corresponding watershed delineation raster. A sampling station missing a delineation raster may not have been properly aligned to its flowline raster.

19. Use the Model Builder tool called **Watershed_rasters_to_polygons_20160824** to convert each watershed raster into its own watershed polygon. These watershed polygons will be named with the FID of the sampling station IDs they correspond to.

20. Use the "Merge" tool[1] to combine all the individual watershed polygons into a single polygon shapefile. The names of the polygons in this shapefile will be the FID of the sampling stations.

Proceed through Steps 21 through 23 for non-nested watersheds to finish delineating the nested watersheds. This concludes the procedures for delineating nested watersheds using ArcMap. Watershed characterization can begin (see Section 4).

[1]Merge: http://pro.arcgis.com/en/pro-app/tool-reference/data-management/merge.htm.

4. Characterization of delineated watersheds

Once all the target watersheds have been delineated, watershed characterization can begin. This manual describes five characterization steps (see Figure 1-1). Using the automated tools described here standardizes processing among agencies and users, reduces human error, expedites processing, and makes results more reproducible. If the tools cannot be run on your computer, this guide also describes the intent and output of the tools so the processes can be implemented by alternative means (manually, modifying the scripts, etc.). (Descriptions of the Python scripts can be found in Section 6.)

4.1. Process overview

Corresponding watershed delineation and sampling station shapefiles are input to tools that calculate or help calculate the following watershed characteristics: (1) the fraction of land under each NLCD land use within the whole watershed and within 1 km and 5 km of the sampling stations within the watershed (i.e., the entirety of the watershed that is within 1 km and 5 km of the sampling station); (2) the percentage of stream flow that comes from the base flow fraction at the sampling station; (3) the channel slope and sinuosity upstream and downstream of the station; (4) the slope of the watershed (average, minimum, maximum, range, standard deviation); and, (5) the number of dams, mines, NPDES, and CERCLA sites within each watershed. The processes that calculate 3 and 5 involve a few minutes of manual processing per station; the processes that calculate 1, 2, and 4 are completely automated. The output of all processes should be checked.

In each process, calculated watershed characteristics become new fields that are added to the attribute table of the state's watershed delineation shapefile. To facilitate data analysis and sharing, it is recommended that the output shapefile from each step be used as an input to the next step. This workflow accumulates watershed property information in the delineation shapefiles. For example, if the delineation shapefile with land use composition is input into the base flow tool, the resulting delineation shapefile will have both land use composition and base flow information. Using the workflow shown in Figure 1-1, the shapefile output from the dam/mine/NPDES/CERCLA step will have fields with the output of all the preceding steps. Additional characterizations can be added after these and the results appended as new columns.

Below are a few general notes about using these tools to help with characterization:

- The sampling stations and watersheds must have the same names in their respective shapefiles, although their field names in their respective shapefiles can have different names (e.g., "StationID" in the station shapefile and "NAME" in the delineation shapefile). This condition should be met if the watershed preprocessing and delineation procedures described in Sections 2 and 3, respectively, are followed.
- The interfaces of the tools default to "StationID" and "NAME" for the names of the fields for the sampling stations and watershed names in the sampling station and watershed shapefiles, respectively. Those should be the names for those fields if the preprocessing and delineation procedures above are followed. The sampling station and watershed names must not have any special characters except for underscores (_). The tools do not work with

any other special characters, which should have been removed during predelineation processing (see Section 2, Step 3).

- Most of the tools require the Spatial Analyst extension. One requires the 3D Analyst extension and ArcGIS Desktop Advanced. Which extensions and licenses are needed for each tool is noted below the tool's input files.
- Each tool displays information about its progress in the "Results" window[1] as it runs (see Figure 4-1). This information is useful for identifying problems if a tool stops prematurely or produces unexpected results.
- Many of the tools automatically append a timestamp in the format of "_YYYYMMDD_HH_MM_SS" to the end of output files. While the time a tool is run does not affect the output, adding this unique identifier to the filename prevents the output from accidentally being overwritten when the tool is rerun with the same data.
- Each tool has further documentation in the user interface, as well as commented code.

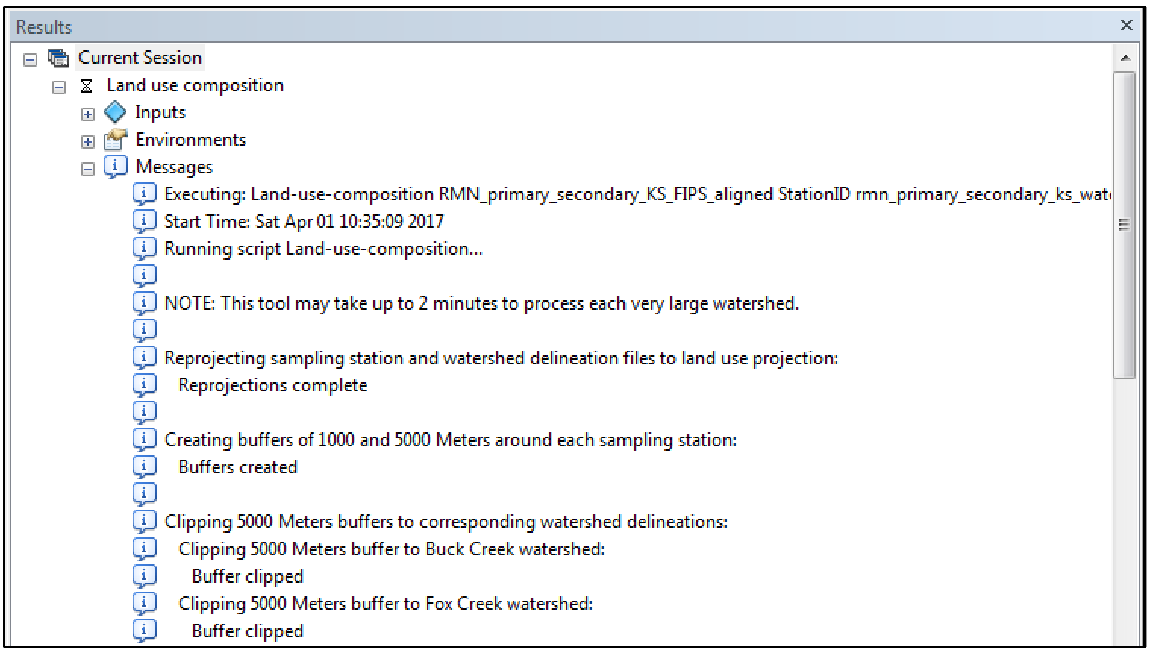


Figure 4-1. Sample Results window output from land use composition tool.

4.2. Loading the tools into ArcMap

The tools have two components: (1) the ArcPy scripts (*.py), and (2) the Regional Monitoring Network toolbox (**Regional_monitoring_network.tbx**) (see Figure 4-2). The former are the actual directions for

[1]Results window: http://desktop.arcgis.com/en/arcmap/10.3/analyze/executing-tools/using-the-results-window.htm.

the tools while the latter tells ArcMap how to create the standard ArcMap geoprocessing interface for the tools. Keep these components in the same folder on your computer.

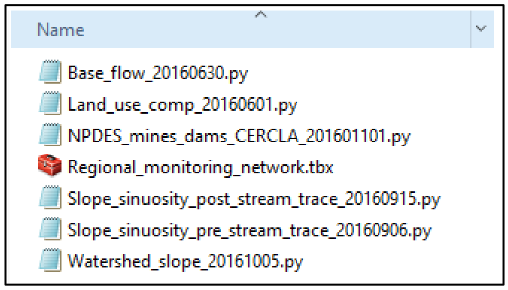


Figure 4-2. List of files included in folder. There is one toolbox (*.tbx) and six tools (*.py).

1. If the tool folder is zipped, unzip it. The folder inside is called "RMN GIS tools".

2. Copy "RMN GIS tools" folder with the RMN geographic information system (GIS) tools inside (*.py scripts and **Regional_monitoring_network.tbx**) to a local directory of your choice.

3. Navigate to that folder in ArcCatalog or the Catalog window of ArcMap. If **Regional_monitoring_network.tbx** is not visible in the folder that it was moved to, right-click on that folder and refresh it (see Figure 4-3).

4. Expand **Regional_monitoring_network.tbx**. Several scripts (e.g., Watershed slope) should appear underneath (see Figure 4-3). You should be able to successfully run these scripts now.

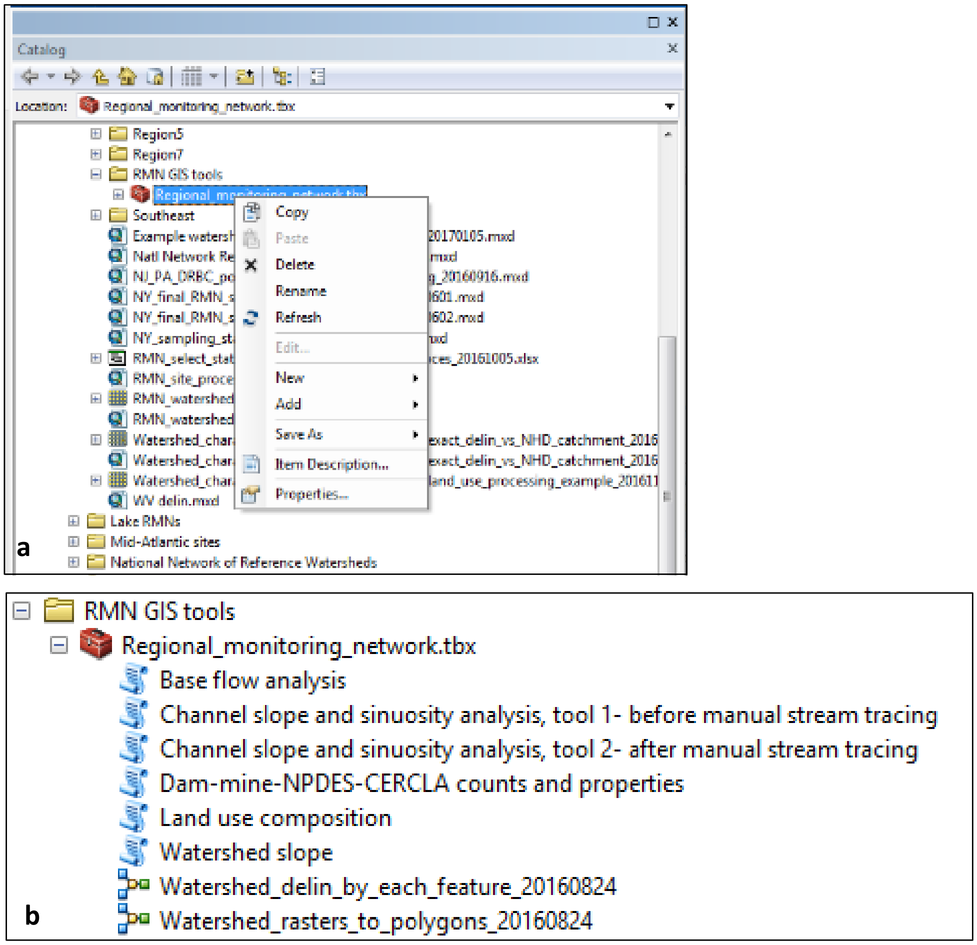


Figure 4-3. Displaying the RMN toolbox in ArcMap. To refresh, right-click on the toolbox (a). The contents of the toolbox are shown in (b).

The tools have the standard ArcMap geoprocessing tool interface.

Each input field has help text associated with it, revealed by clicking the Show Help >> button in the bottom right of the tool. Right-clicking on each tool in the catalog and clicking on “Item Description” will also provide more information.

4.3. Characterization

If you have not already done so, activate the Spatial Analyst and 3D Analyst extensions in ArcMap under Customize > Extensions and check Spatial Analyst and 3D Analyst. You will need them to run some of the watershed characterization tools.

Below are descriptions of the five characterization processes.

4.3.1. Land use composition

Objective:

To calculate the fraction of each land use within: (1) each RMN watershed, (2) 1,000 m of each sampling station in its watershed, and (3) 5,000 m of each sampling station within its watershed.

NOTE: If other distances are desired, the values can be changed in the script.

Data use:

Land use is one of the primary characteristics for assessing whether a watershed is a "reference" watershed. Reference watersheds have low fractions of developed and agricultural land and high fractions of natural land. This step of screening allows assessment of what fraction of each RMN watershed is "natural" versus "disturbed" within certain distances of RMN sampling stations. Different levels of "developed" (i.e., land use codes (LUC) 22, 23, 24) or agricultural land uses (i.e., LUC 81 and 82) can be summed to produce totals for different disturbed categories.

Required input files:

1. Sampling stations aligned to flowline raster: **RMN_primary_secondary_[STATEABBRV]_reproj_aligned.shp**
2. Watershed delineations with added characterizations thus far
3. NLCD land use raster[1] (land use codes must be the same as the 2006/2011 NLCD codes[2]). You do not need to do any processing of the downloaded NLCD raster before running this watershed characterization tool. The tool will handle differences in projections between the raster and shapefiles.

NOTE: This tool requires the Spatial Analyst extension (for the "Extract by Mask" command).

Output:

1. Watershed delineation shapefile with one field added for each land use-area extent combination (whole watershed, 1,000 m, and 5,000 m). All added fields have the fraction of that land use at that extent. Added fields are named according to the following scheme: LU[LUC]_[DISTANCE] (bracketed text is variable), where [LUC] is the NLCD land use code (e.g., 11, 72) and [DISTANCE] is 1,000, 5,000, or "whole." Thus, the field titled "LU71_whole" shows the fraction of each watershed comprised of NLCD land use 71 and "LU11_1000" shows the fraction of each watershed within 1,000 m of the sampling stations comprised of NLCD land use 11.

Procedures:

Fill out the tool interface as each field directs (see Figure 4-4). See the tool help for more information.

---

[1]National Land Cover Database (NLCD): https://www.mrlc.gov/nlcd06_data.php.
[2]NLCD 2006/2001 codes: http://www.mrlc.gov/nlcd11_leg.php.

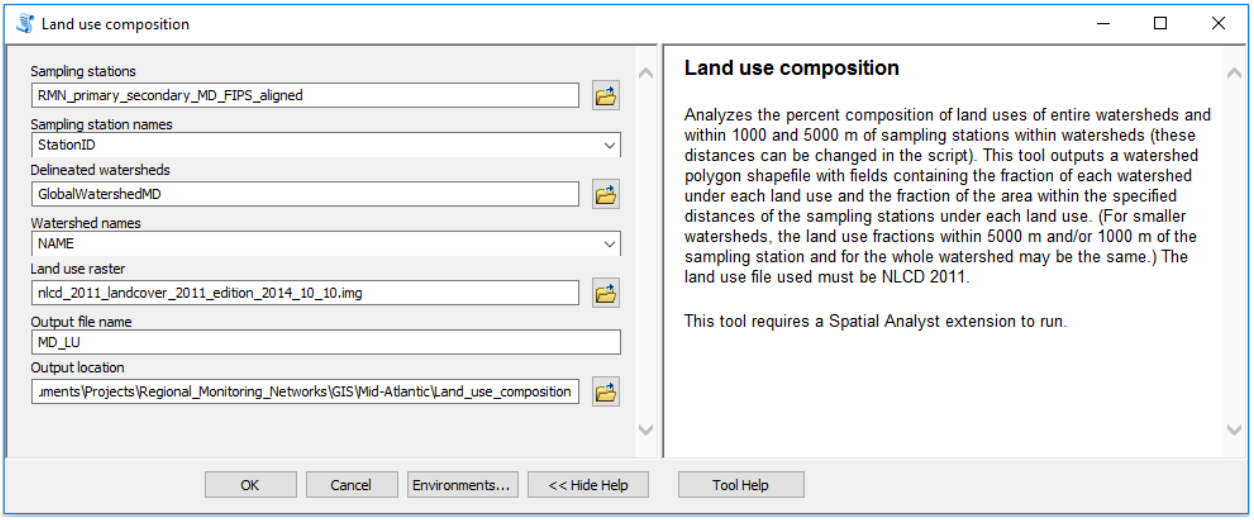


Figure 4-4. Interface for land use composition tool. NOTE: tool interfaces may not appear exactly as shown in this manual due to subsequent modification.

4.3.2. Base flow

Objective:

To calculate the base flow index at RMN sampling stations (i.e., at the mouth of each watershed).

Data use:

Base flow index (percentage) indicates what percentage of the streamflow at that location originates from base flow. The index can be useful for determining how consistent streamflow is at that location and how changes in precipitation are likely to impact stream hydrology. Streams with high base flow index are more resistant to precipitation variability. Different fish and macroinvertebrate taxa have varying sensitivities to hydrological alteration.

Required input files:

1. Sampling stations aligned to flowline raster: **RMN_primary_secondary_[STATEABBRV]_reproj_aligned.shp**
2. Watershed delineations with added characterizations thus far
3. USGS base flow raster[1] (scale of 0–100). You do not need to do any processing of the downloaded base flow raster before running this watershed characterization tool. The tool will handle differences in projections between the raster and shapefiles.

NOTE: This tool requires the Spatial Analyst extension (for the "Extract Values to Points" command).

[1]USGS base flow raster: https://water.usgs.gov/GIS/metadata/usgswrd/XML/bfi48grd.xml.

Output:

1. Watershed delineation shapefile with a single field added ("BASE_FLOW") that contains the value of the base flow index raster beneath the sampling station.

Procedures:

Fill out the tool interface as each field directs (see Figure 4-5). See the tool help for more information.

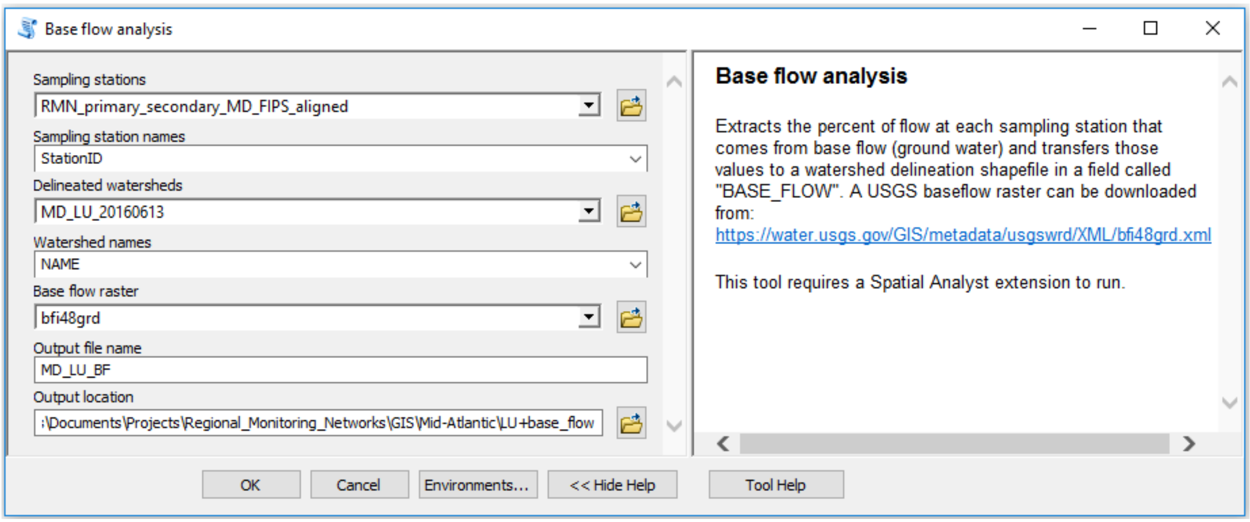


Figure 4-5. Interface for base flow tool.

4.3.3. Channel slope and sinuosity

Objective:

To calculate the channel slope and sinuosity within user-specified distances upstream and downstream of RMN sampling stations. Channel slope is the change in elevation along a given stream channel length divided by the channel segment length. Channel sinuosity is the length of a segment of channel divided by the straight-line distance from one end of that channel segment to the other.

Data use:

Channel slope and sinuosity are useful for classifying streams, which is one of the key potential classification parameters used for RMN stations. They are also useful for screening out channels that do not match RMN stream type targets.

Procedures overview (see Figure 4-6):

This characterization uses three processes, each with its own inputs and outputs:

1. Run the first custom tool to prepare to create stream traces (trace preprocessing),

2. Manually create stream traces, and
3. Run the second custom tool to calculate channel slope and sinuosity from the stream traces.

Calculating channel slope and sinuosity requires having polylines that follow the mainstem of streams at specific distances upstream and downstream from the sampling stations (i.e., stream traces). Creating those stream traces is better done by humans than a by computer algorithm because tracking the mainstem involves extensive situational awareness. Thus, these procedures describe manual stream tracing.

The two custom tools developed for channel slope and sinuosity allow users to manually trace each stream once, then calculate channel slope and sinuosity over different distances (trace lengths) simply by running the second tool on the stream traces again with a different trace length input (explained further below). This promotes experimenting with slope and sinuosity over different channel lengths to see what lengths best characterize these channel properties. Total trace lengths of 1,000 and 2,000 m are standard for RMN sites.

NOTE: The first custom tool requires the Spatial Analyst extension (for the “Extract by Mask” command). The second custom tool requires the 3D Analyst extension (for “Interpolate Shape” command) and the ArcGIS Desktop Advanced license (for “Split Line at Point” command).

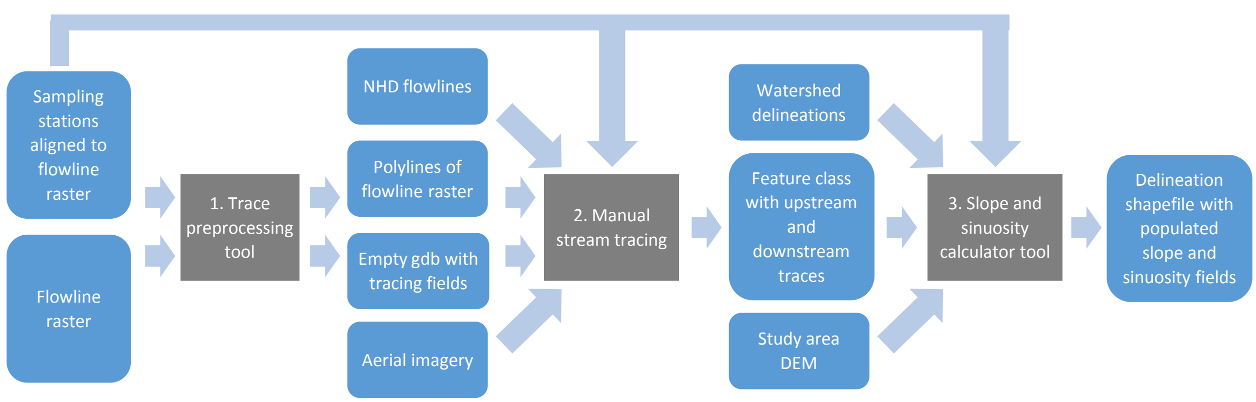


Figure 4-6. Schematic of the channel slope and sinuosity workflow. Shapes with rounded corners are files; shapes with sharp corners are processes (manual or automated).

Part 1 input and output files (manual stream tracing precursor tool):

Input:

1. Sampling stations aligned to flowline raster: **RMN_primary_secondary_[STATEABBRV]_reproj_aligned.shp**

2. Flowline raster

Output:

1. Geodatabase (**slope_sin_[STATEABBRV]_[YYYYMMDD_HH_MM_SS].gdb**) with two feature classes: flowlines rasters within a 2,000-m radius of sampling stations converted into polyline feature class (**flow_polylines_[STATEABBRV]_[YYYYMMDD_HH_MM_SS]**), and an empty feature class with fields useful for creating stream trace polylines (**stream_traces_full_length_[STATEABBRV]_[YYYYMMDD_HH_MM_SS]**).

Part 2 input and output files (manual stream tracing):

Input:

1. Sampling station aligned to flowline raster: **RMN_primary_secondary_[STATEABBRV]_reproj_aligned.shp**
2. Polylines of flowline raster, created in Part 1 (**flow_polylines_[STATEABBRV]_[YYYYMMDD_HH_MM_SS]**)
3. Empty feature class with useful fields for tracing, created in Part 1 (**stream_traces_full_length_[STATEABBRV]_[YYYYMMDD_HH_MM_SS]**)
4. Aerial imagery
5. NHD flowlines

Output:

1. Feature class in geodatabase populated with one upstream stream trace feature and one downstream stream trace feature for each sampling station, starting at the sampling stations (**stream_traces_full_length_[STATEABBRV]_[YYYYMMDD_HH_MM_SS]**)

Part 3 input and output files (slope and sinuosity calculator tool):

Input:

1. Sampling stations aligned to flowline raster: **RMN_primary_secondary_[STATEABBRV]_reproj_aligned.shp**
2. Watershed delineations with added characterizations thus far
3. Manually created stream traces, created in Part 2 (**stream_traces_full_length_[STATEABBRV]_[YYYYMMDD_HH_MM_SS]**)
4. DEM to the extent of the study area

Output:

1. Feature class in the trace geodatabase with additional values used to calculate slope and sinuosity for each trace (**traces_with_slope_sin_[STATEABBRV]_[DISTANCE]_[YYYYMMDD_HH_MM_SS]**).
2. Watershed delineation shapefile with fields added for: channel sinuosity (“sinDISTANCEm”), channel slope(“slpDISTANCEm”), notes (“SSNts[DISTANCE]”) (empty), meters of elevation

change over the distance (“mChng[DISTANCE]”), and the trace length over the distance (“trc[DISTANCE]”).

Procedures by part:

Part 1: Run the first custom tool to prepare to create stream traces.

1. Fill out the interface for the tool called “Channel slope and sinuosity analysis, tool 1- before manual stream tracing” as each field directs (see Figure 4-7). See the tool help for more information. Running this tool creates two files inside the geodatabase named **slope_sin_[STATEABBRV]_[YYYYMMDD_HH_MM_SS].gdb**. One file is all flowline rasters within a 2,000-m radius of each sampling station converted into polylines (**flow_polylines_[STATEABBRV]_[YYYYMMDD_HH_MM_SS]**); these polylines are used for stream tracing. The other is an empty feature class (**stream_traces_full_length_[STATEABBRV]_[YYYYMMDD_HH_MM_SS]**) that you will populate with stream traces during the manual stream tracing procedure (see Part 2). This tool creates this second feature class so that all stream trace files have fields with the same names and properties. This automatic naming helps to standardize procedures across users and agencies. The flowline raster can either be downloaded from StreamStats (preferred) or created in Step 9 of Section 3.2.

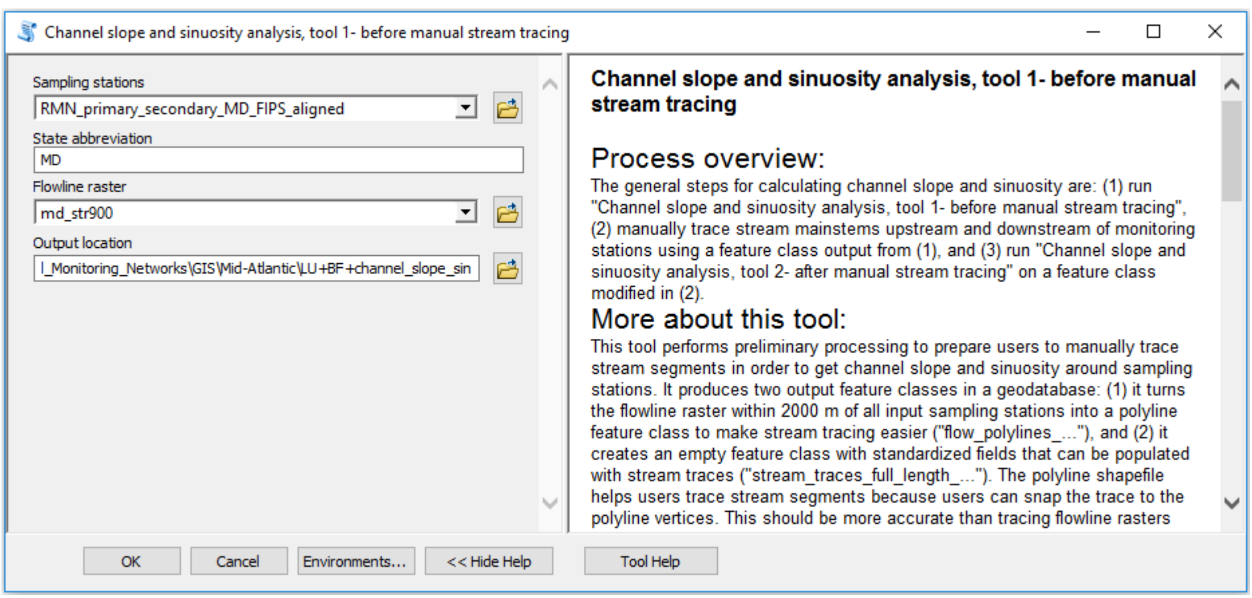


Figure 4-7. Interface for tool to do the first part of calculating channel slope and sinuosity (before manual stream tracing).

Part 2: Manually create stream traces.

1. Load **stream_traces_full_length_[STATEABBRV]_[YYYYMMDD_HH_MM_SS]**, **RMN_primary_secondary_[STATEABBRV]_reproj_aligned.shp**, **flow_polylines_[STATEABBRV]_[YYYYMMDD_HH_MM_SS]**, and basemap aerial imagery

into the Table of Contents. These are the files necessary for doing stream tracing. Additionally, NHD flowlines may be helpful and can also be added to the Table of Contents.

2. Make **stream_traces_full_length_[STATEABBRV]_[YYYYMMDD_HH_MM_SS]** editable and open the "Create Features" window[1] under the Editor > Editing Windows menu. Select **stream_traces_full_length_[STATEABBRV]_[YYYYMMDD_HH_MM_SS]** in the "Create Features" window and open its attribute table.

3. Zoom to the first sampling station in the sampling station shapefile. It might help to change the sampling stations' symbology to something large and visible, like . Make the symbology of **flow_polylines_[STATEABBRV]_[YYYYMMDD_HH_MM_SS]** thick and visible, like . Make the symbology of **stream_traces_full_length_[STATEABBRV]_[YYYYMMDD_HH_MM_SS]** somewhat thinner and a different color, like . Make sure that **stream_traces_full_length_[STATEABBRV]_[YYYYMMDD_HH_MM_SS]** is above **flow_polylines_[STATEABBRV]_[YYYYMMDD_HH_MM_SS]** in the Table of Contents so that traces are visible on top of the flowlines as they are created. ArcMap may look like Figure 4-8a.

4. Click on **stream_traces_full_length_[STATEABBRV]_[YYYYMMDD_HH_MM_SS]** in the "Create Features" window, snap the vertex held by the mouse to the sampling station, and click there. If you do not have snapping enabled, then enable[2] it. (NOTE: It is critical that all stream traces—both upstream and downstream—start exactly at sampling stations and that all sampling stations have one upstream and one downstream trace emanating from them.) Then trace the flowline one direction from the sampling station for at least 1,500 stream meters, if possible (see Figure 4-8b). The stream trace feature class will update each trace's length when you finish that trace.

[1]Create features: http://pro.arcgis.com/en/pro-app/help/editing/introduction-to-creating-2d-and-3d-features.htm.
[2]Enable snapping: http://desktop.arcgis.com/en/arcmap/10.3/manage-data/editing-fundamentals/enabling-snapping-classic-snapping-.htm.

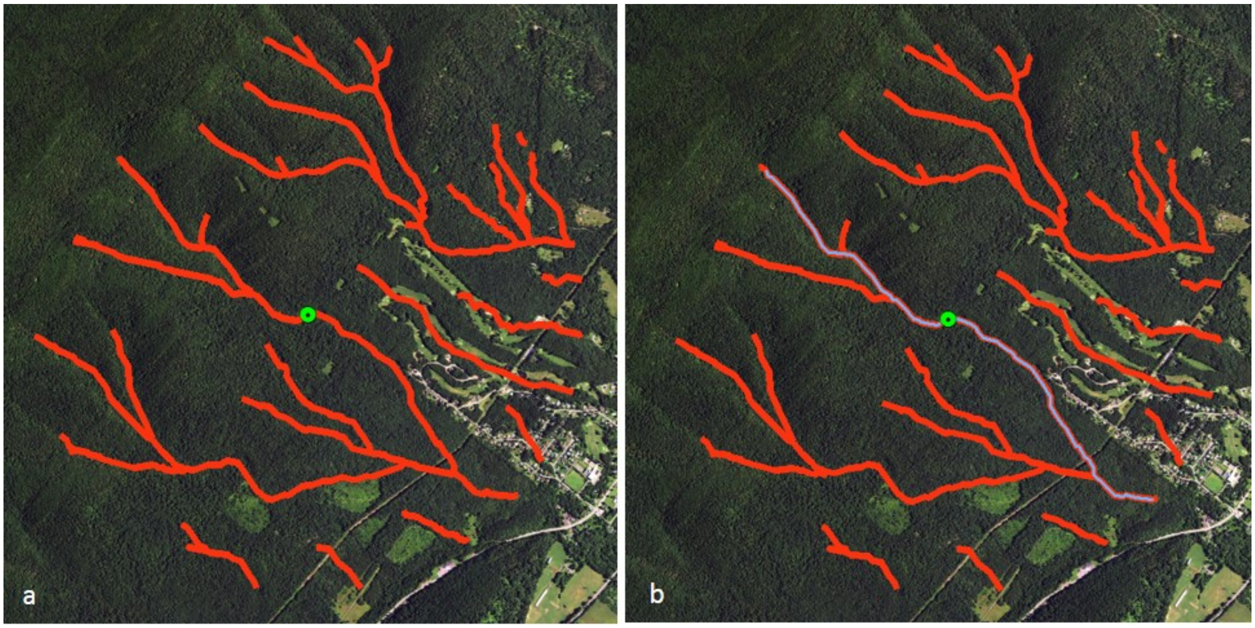


Figure 4-8. (a) Polylines of flowline raster with sampling station and aerial imagery. (b) Polylines of flowline raster with stream trace upstream and downstream to the extent of the polyline flowlines (2,000 m each direction).

NOTES on stream tracing:

- Whenever the flowline does not match the actual stream according to aerial imagery, trace the actual stream, not the flow polyline. The flow polyline is just a convenience to make tracing faster and more consistent when the trace matches the stream.
- Tracing must start exactly at the sampling stations and work outwards (i.e., the starts of the stream traces must be snapped to the aligned sampling station). Traces cannot start away from sampling stations and end at them.
- You can snap the vertices of the stream trace to the flowline to ensure that the trace matches the flowline. In general, the flowlines should correctly follow actual streams if the flowlines are derived from the StreamStats flowline rasters. If the flowlines were created from a DEM using ArcMap geoprocessing tools, flowlines may not follow actual streams as well as they do for the StreamStats flowlines so you may need to compare them more closely with aerial photographs and NHD flowlines and adjust accordingly.
- To reduce the risk of error, it is recommended you trace sites sequentially (i.e., trace both directions at one site before moving to the next) and consistently trace one direction at each site before tracing the other direction (e.g., always trace upstream at a site before tracing downstream).
- Stop tracing streams whenever they reach a lake, dam, a coastline, visibly larger river, or anything else that would change channel slope or sinuosity dramatically (see Figure 4-9). For

example, channel sinuosity is meaningless inside lakes or ponds. Use aerial imagery to look for these disruptions.

- When tracing upstream, it may be difficult to tell which branch is the mainstem. Generally, choose the branch that appears to have more stream length based on the raster flowlines and NHD.
- Make sure that stream traces are sequentially numbered in the trace feature class. There should be no gaps in the OBJECTID field. Gaps in the OBJECTID field can be caused by creating a trace, then deleting it. If any gaps do appear, one way to remove them is to save the edits to your traces, leave editing mode, copy the feature class into a shapefile, edit the duplicate ID numbers in the shapefile to be sequential, and copy the shapefile back into a new stream trace feature class.
- If the sampling station is located at some discontinuity in the stream channel (e.g., on a confluence with larger river, at the coast, entrance to or exit from a lake, etc.), include a token trace (even 1 m) in the direction of the disruption. For the slope and sinuosity calculations to work, there must be one trace for each direction at each station no matter how short it is.
- A good magnification for tracing is between 1:8,000 and 1:12,000.
- Save your stream traces frequently within editor mode.

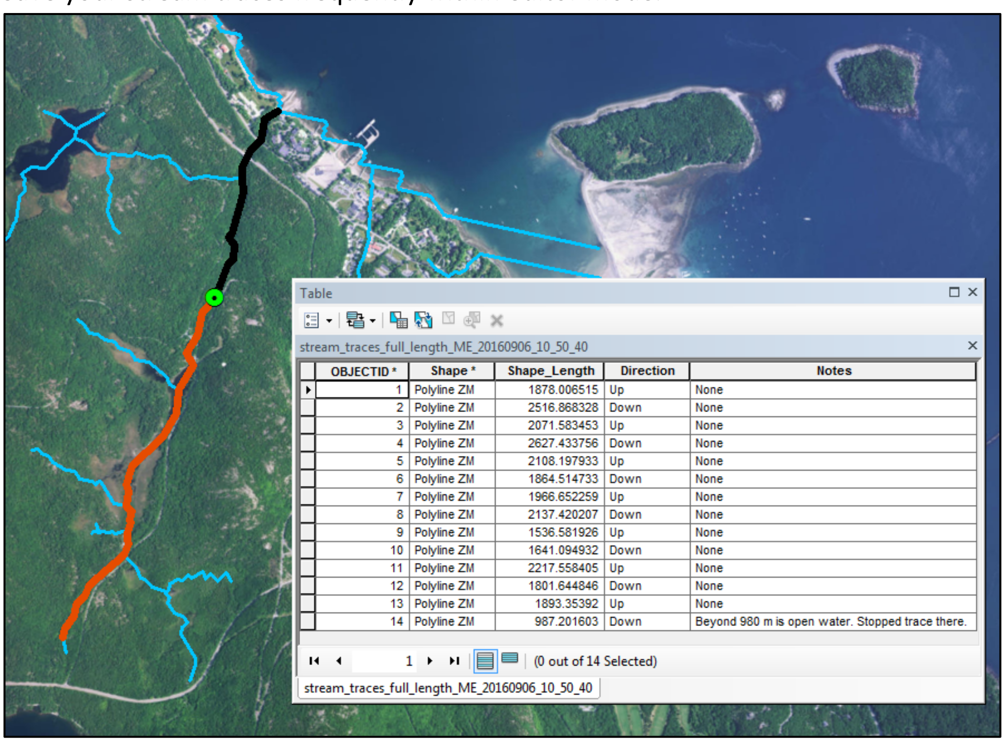


Figure 4-9. Example of a stream trace stopped at a lake. The green circle is the sampling station, the black line is the downstream trace stopping at the lakeshore, the red line is the upstream trace, and the thin blue lines are the polyline flowlines. The last visible row of the attribute table notes that the trace stopped at a lake.

5. After you complete each trace, note whether that trace went "Up" or "Down" in the "Direction" field of **stream_traces_full_length_[STATEABBRV]_[YYYYMMDD_HH_MM_SS]**. In the "Notes" field, note whether you had to stop tracing within the flowlines provided by the pre-trace tool due to coastline, lakes, confluences with visibly larger rivers, and so on. This will inform subsequent users why some traces are shorter than expected (see Figure 4-10).

	42	Polyline ZM	514.468246	Down	Lake begins 520 m downstream of station. Stopped trace there.
	43	Polyline ZM	246.088837	Up	Lake 250 m upstream of station. Stopped trace there.
	44	Polyline ZM	1539.437574	Down	Lake 1550 m downstream of station. Stopped trace there.
	45	Polyline ZM	1424.485222	Up	None
	46	Polyline ZM	2307.522281	Down	None
	47	Polyline ZM	1725.354816	Up	None
	48	Polyline ZM	2411.322419	Down	None
	49	Polyline ZM	808.470326	Up	Traced to upstream end of StreamStats stream grid

Figure 4-10. Sample of trace geodatabase with trace direction and notes.

6. Once all traces have been completed (twice the number of sampling stations), save the edits to your trace feature class and exit editor mode.
7. Confirm that each sampling station has one upstream trace and one downstream trace and that the traces are numbered sequentially.

NOTE: The slope and sinuosity calculator will not work properly if traces are not numbered sequentially and each station does not have two traces snapped to it.

Part 3: Run the second custom tool to calculate channel slope and sinuosity from the stream traces.

1. Fill out the interface for the tool called "Channel slope and sinuosity analysis, tool 2- after manual stream tracing" as each field directs (see Figure 4-11). If the RMN watersheds are contained within one NHD subregion, input that DEM. If the RMN watersheds span multiple NHD subregions, the input DEM was composited in Section 3.1, Step 14 (for StreamStats delineations) or Section 3.2, Step 1 (for ArcMap delineations). Standard values for "Trace length in either direction" for the RMN are 500 and 1,000 m. The tool's default vertical units are centimeters because the NHD DEM units are centimeters.

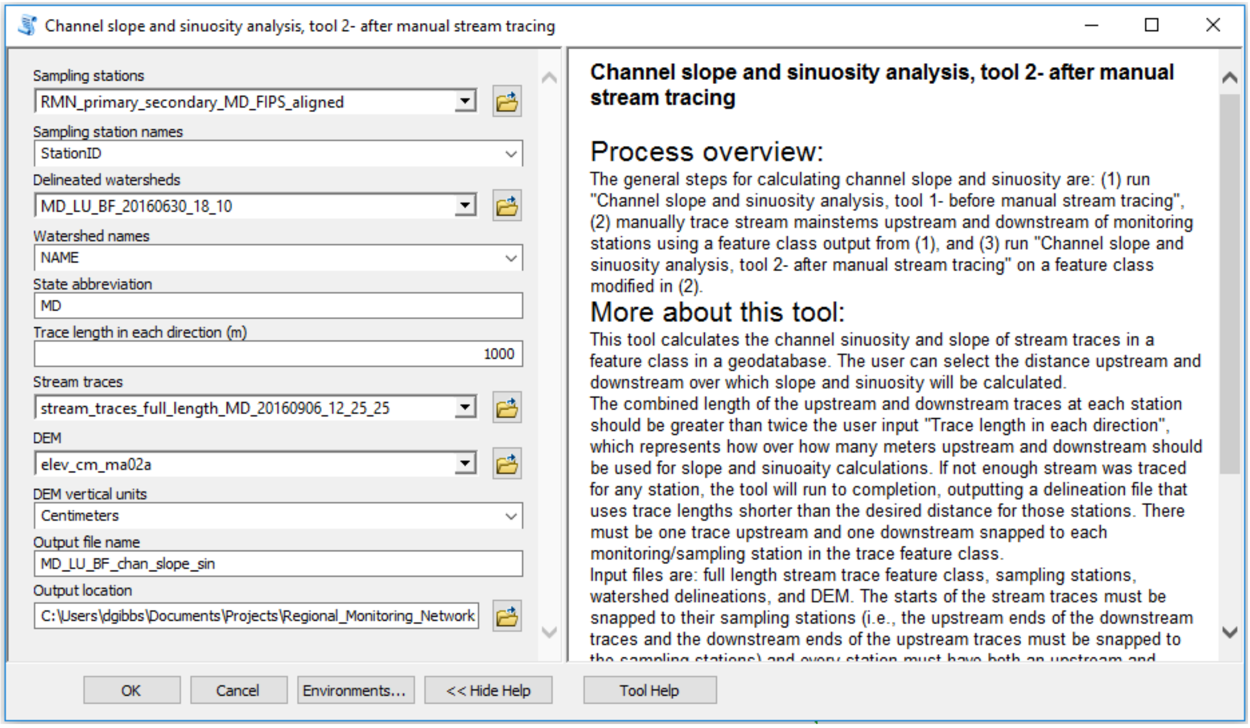


Figure 4-11. Interface for tool to calculate channel slope and sinuosity (after manual stream tracing).

NOTE: This tool looks for adequate “Trace length in each direction” in both directions (upstream and downstream of the sampling station). If there is not enough trace length in one direction, it will add length to the other direction to make up the difference. If there is not enough trace length in both directions combined, the ArcMap Results display will tell users, and the output field “trc[DISTANCE]m” will display the deficient trace length for that feature. For example, if the input “Trace length in each direction” is 500 m and a station has traces of 472 m and 976 m, the resulting traces will be 472 m and 528 m. If the traces are 482 m and 405 m, all of both traces will be used for the channel slope and sinuosity calculations but the total trace length will only be 887 m, not 1,000 m.

2. This tool produces two output files.

   a. One is a feature class in the geodatabase called **traces_with_slope_sin_[STATEABBREV]_m_[DISTANCE]_[YYYYMMDD_HH_MM_SS]**. For each watershed, this line feature class provides information on: how long the trace is (field “Shape_Length”), the starting and ending *X* and *Y* coordinates, the straight-line distance from the start to the end of the trace (field “strgt_dist”), the channel sinuosity over that distance (field “sinuosity”), the starting and ending elevations of the trace in meters (fields “startElevM” and “endElevM”, respectively), the change in elevation over the trace (field “elevChng_m”), and the channel slope (field “chan_slope”). This file contains fields useful for quality control and confirming the tool’s output (see Figure 4-12). The most useful field to examine for quality control is “Shape_Length”; if it does not equal the total desired trace distance for a station, something is amiss and the relevant traces need to be investigated. Moreover, the "strgt_dist" should always be less than the "Shape_Length" and the latter divided by the former should equal the sinuosity. "elevChng_m" should be the difference between "startElevM" and "endElevM", and one-one-hundredth of the difference between "startElev" and "endElev" (elevations in centimeters).

b. The other output file is a shapefile in the user-specified output folder. This file has all the fields of the input watershed delineation shapefile with channel slope and sinuosity (fields "sin[DISTANCE]m" and "slp[DISTANCE]m", respectively), the change in elevation over the trace (field "mChng1000"), the trace length (field "trc[DISTANCE]m"), and a notes field (field "SSNts[DISTANCE]m").

traces_with_slope_sin_ME_m_1000_20160919_14_10_35

StationID	Shape_Length	start_x	start_y	end_x	end_y	strgt_dist	sinuosity	startElev	endElev	startElevM	endElevM	elevChng_m	chan_slope
17	1000.000051	1999102.3866	2700570.1472	1998261.4962	2701081.4296	984.127206	1.016129	19226.28	18820.4	192.2628	188.204	4.0588	0.004059
346	999.999871	1985495.8101	2676848.7826	1985271.9076	2677719.4068	898.954296	1.112403	22261.06	21782.9	222.6106	217.829	4.7816	0.004782
56817	1000.000148	2076386.5486	2649092.6315	2076578.869	2650024.9422	951.940322	1.050486	3151.96	3134.47	31.5196	31.3447	0.1749	0.000175
57011	1000.000042	2076395.8101	2666241.3108	2076945.8917	2666830.4701	806.038738	1.240635	7559.01	6879.99	75.5901	68.7999	6.7902	0.00679
57065	1000.000004	2174766.2588	2697688.1818	2174863.9062	2698628.6448	945.51873	1.057621	6204.29	2572.95	62.0429	25.7295	36.3134	0.036313
626	999.999834	2115238.6785	2671573.8553	2115757.765	2671668.6786	527.676276	1.895101	3671.87	3643.39	36.7187	36.4339	0.2848	0.000285
MEDEP_57	999.999952	2050058.7293	2726589.6429	2050380.9324	2727450.2199	918.916542	1.088238	15811.22	14977.89	158.1122	149.7789	8.3333	0.008333

Figure 4-12. Sample attribute table for traces_with_slope_sin_[STATEABBREV]_m_[DISTANCE]_[YYYYMMDD_HH_MM_SS].

3. Check the "trc[DISTANCE]m" field in the output shapefile to make sure that all traces are within rounding error of the desired trace distance (e.g., if the "Trace length in each direction" input was 500, "trc[DISTANCE]m" values should be between 999.9 and 1,000.1). If any values are less than twice the input value, check whether the upstream and downstream traces for that sampling station are collectively less than the trace length objective. If there are any surprising results, also confirm that the starts of the traces are snapped[1] to their sampling stations.

[1]Details on snapping points: http://desktop.arcgis.com/en/arcmap/10.3/manage-data/editing-fundamentals/about-snapping.htm.

4. If you want to check any distance measurements output by the tool, make sure that the dataframe's projection[1] is the same as that of the DEM. Otherwise, the distances found by the Ruler tool will not match the tool's outputs. You can change the dataframe projection in the dataframe properties menu. (NOTE: The channel slope-sinuosity tool calculates planar distances.)

5. If it is not possible to collectively trace upstream and downstream far enough to provide the total desired distance (e.g., upstream encountered the end of the flow grid and downstream encountered a lake), note in the "SSNts[DISTANCE]m" field of the output shapefile that the total trace was expected to be short and that the slope and sinuosity calculations are over a shorter distance than the other values (see Figure 4-13, red box). This will assist other users who subsequently use the watershed delineation shapefile.

sin2000m	slp2000m	trc2000m	mChng2000	SSNts2000m
2.008035	0.010032	1999.999987	20.0632	None
1.136444	0.003476	2000	6.9515	None
1.088207	0.004117	2000.000073	8.2339	None
1.172475	0.048824	2000.000022	97.6477	Downstream trace was 80 m to a lake; upstream trace was 1920 m
1.157609	0.030306	1999.999982	60.611	None
1.193147	0.004882	1999.999981	9.7641	None
1.168206	0.010667	1999.999987	21.334	Downstream trace was 20 m to a lake; upstream trace was 1980 m
1.270575	0.054683	1999.999938	109.3666	None
1.038684	0.118255	2000.00005	236.5102	None
1.382398	0.04496	1362.334479	61.2506	Total trace length is 1362 m because downstream trace reaches a tlake in 15 m and upstream trace reaches end of StreamStats grid

Figure 4-13. Partial output of watershed delineation shapefile with channel slope and sinuosity, calculated over 2,000 m stream traces wherever possible. Note in the final row (red box) that the total trace length was only 1,362 m because of obstacles to the traces upstream and downstream. In the two rows with blue boxes, the total trace lengths are 2,000 m but the notes field says that they are not evenly split between upstream and downstream traces.

6. If it is not possible to trace in one direction far enough to provide the desired distance but it is possible to trace the other direction far enough to compensate, note in the "SSNts[DISTANCE]m" field that the slope and sinuosity calculations used traces of unequal length (i.e., did not use equal length upstream and downstream traces) (see Figure 4-13, blue boxes). This will assist other users who subsequently use the watershed delineation shapefile.

7. If you want to calculate channel slope and sinuosity over another trace length, repeat Part 3 with the new value in the "Trace length in each direction" input field. If you want the new channel slope and sinuosity values in the same watershed delineation file as the previous values, use the output delineation shapefile from the first run as the input delineation shapefile from the second run. As long as the "Trace length in each direction" field is different, the tool will create new fields in the output shapefile. It will also create a new feature class in the geodatabase with the new desired trace distance and the unique time

[1]Dataframe projection: http://support.esri.com/technical-article/000005357.

stamp (see Figure 4-14) (**traces_with_slope_sin_[STATEABBREV]_m_[DISTANCE]_[YYYYMMDD_HH_MM_SS]**).

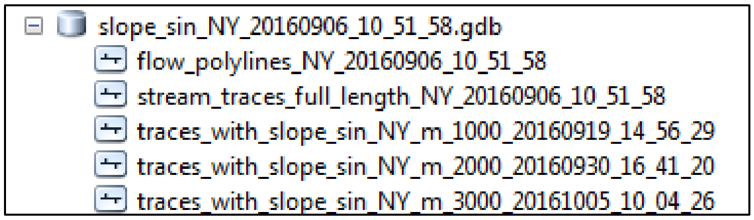


Figure 4-14. Channel slope-sinuosity geodatabase with the polyline versions of the flowline rasters created in Part 1 of this analysis, the manual stream traces created in Part 2 of this analysis, and the files with slope and sinuosity calculated over three stream distances (500 m, 1,000 m, and 1,500 m each direction).

4.3.4. Watershed slope

Objective:

To calculate the mean, minimum, maximum, range, and standard deviation of watershed slopes. Watershed slope is the slope of the land in each watershed, as opposed to the slope of the stream channel.

Data use:

These watershed slope values, especially the average, can help with classifying watersheds by their slopes, in addition to the values calculated by the channel slope tool. For example, an analysis may be done on only low-gradient watersheds.

Required input files:

1. Sampling stations aligned to flowline raster: **RMN_primary_secondary_[STATEABBRV]_reproj_aligned.shp**
2. Watershed delineations with added characterizations thus far
3. DEM to the extent of the study area

NOTE: This tool requires the Spatial Analyst extension (for “Slope” and “Zonal Statistics as Table” commands).

Output:

1. RMN watershed delineation shapefile with five fields added with the following values for each watershed: slope mean, minimum, maximum, range, and standard deviation (fields “avg_ShdSlp”, “min_ShdSlp”, “max_ShdSlp”, “rng_ShdSlp”, and “std_ShdSlp”, respectively).

Procedures:

Fill out the tool interface as each field directs (see Figure 4-15). If the RMN watersheds are contained within one NHD subregion, input that DEM. If the RMN watersheds span multiple NHD subregions, the input DEM was composited in Section 3.1, Step 14 (for StreamStats delineations) or Section 3.2, Step 1 (for ArcMap delineations).

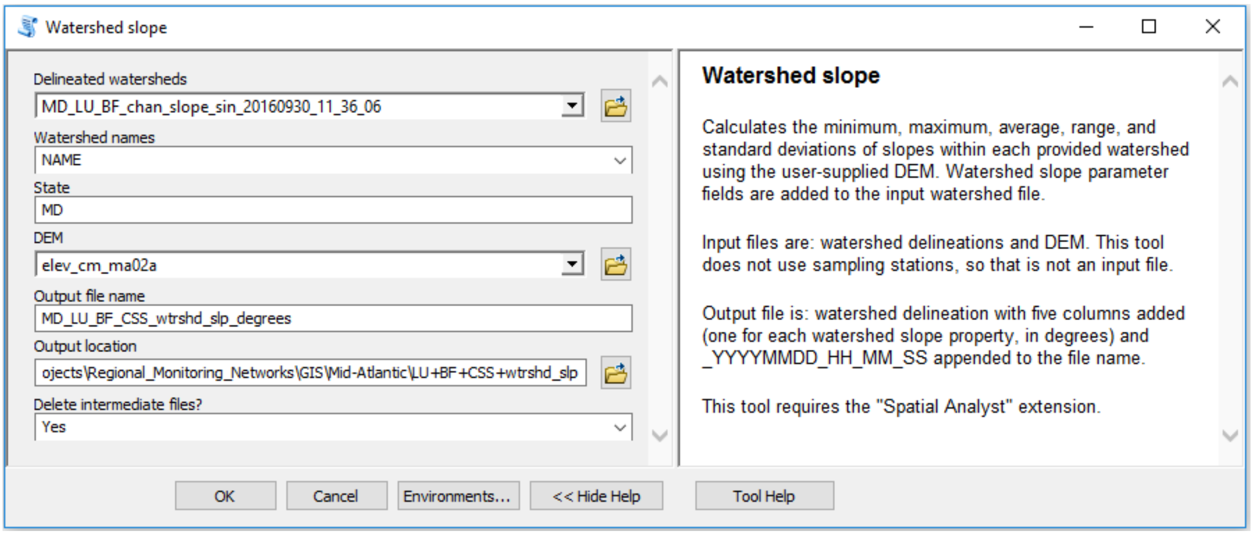


Figure 4-15. Watershed slope tool interface.

4.3.5. Dams, mines, NPDES, and CERCLA site preprocessing

Objective:

To determine how many dams, mines, NPDES, and CERCLA sites are located within each watershed.

Data use:

Watersheds with more of these sites may be more likely to have altered hydrology or water quality and have increased human activity. Thus, they may not be good candidates for reference sites. However, sites in these categories found in a given RMN watershed should be investigated because their source databases may be out-of-date, they may be small or far from the sampling station, or they may not have substantial water quality or flow impacts. Thus, watersheds should not be excluded from “reference” status just because they contain these sites; each situation must be further explored.

Required input files:

Part 1 input and output files (manual site identification precursor tool):

Input:

1. Watershed delineations with added characterizations thus far

Output:

1. Watershed delineations with added characterizations thus far with eight fields necessary for noting relevant sites in watersheds: a count field ("_ct") and a notes field ("_info") for each of the four site types.

Part 2 input and output files (manual site identification):

Input:

1. Sampling stations aligned to flowline raster: **RMN_primary_secondary_[STATEABBRV]_reproj_aligned.shp**
2. Watershed delineations output from manual site identification precursor tool
3. Shapefile of dams from the USGS[1] or a detailed, local file
4. Shapefile of mines from the USGS[2] or a detailed, local file
5. Shapefile of NPDES sites[3] from the EPA or a detailed, local file
6. Shapefile of CERCLA sites[3] from the EPA or a detailed, local file

Output:

1. RMN watershed delineation shapefile with the eight new fields populated (four site types, each with a count field and a notes field)

Procedures:

NOTE: RMN watersheds are designated in areas where there are minimal human impacts. Thus, they should have few dams, mines, NPDES, and CERLCA sites. The methods described here would be more cumbersome for watersheds that are not selected to minimize the numbers of these sites.

1. Fill out the tool interface as each field directs (see **Error! Reference source not found.**). See the tool help for more information. Using this tool quickly adds eight standardized fields to the input watershed file; it does not actually determine the number of each site type in each watershed. That part must be done manually, following use of this tool. Recording how many of each site type is in each watershed is deliberately not included in the tool because this determination is best done using human discretion, and the absence of automatic calculation forces the user to personally check and annotate sites.

2. Add shapefiles for dams, mines, NPDES, and CERCLA to the Table of Contents.

3. Use the "Select by Location" interface to select all dams, mines, NPDES, and CERCLA sites that "are within a distance of the source layer feature" of the watershed file output by this tool (see **Error! Reference source not found.**). Set the search distance to 500 ft. Including this buffer around the watersheds will make sure that any sites whose coordinates are just

[1]USGS major dams shapefile: https://catalog.data.gov/dataset/usgs-small-scale-dataset-major-dams-of-the-united-states-200603-shapefile.
[2]USGS mines shapefile: https://mrdata.usgs.gov/metadata/mineplant.faq.html.
[3]EPA sites of interest: https://www.epa.gov/enviro/geospatial-data-download-service.

outside the watershed but might actually be inside to due data inaccuracies can be assessed.

4. Check each of the four site shapefiles to see if any sites were selected (i.e., are within the watersheds).

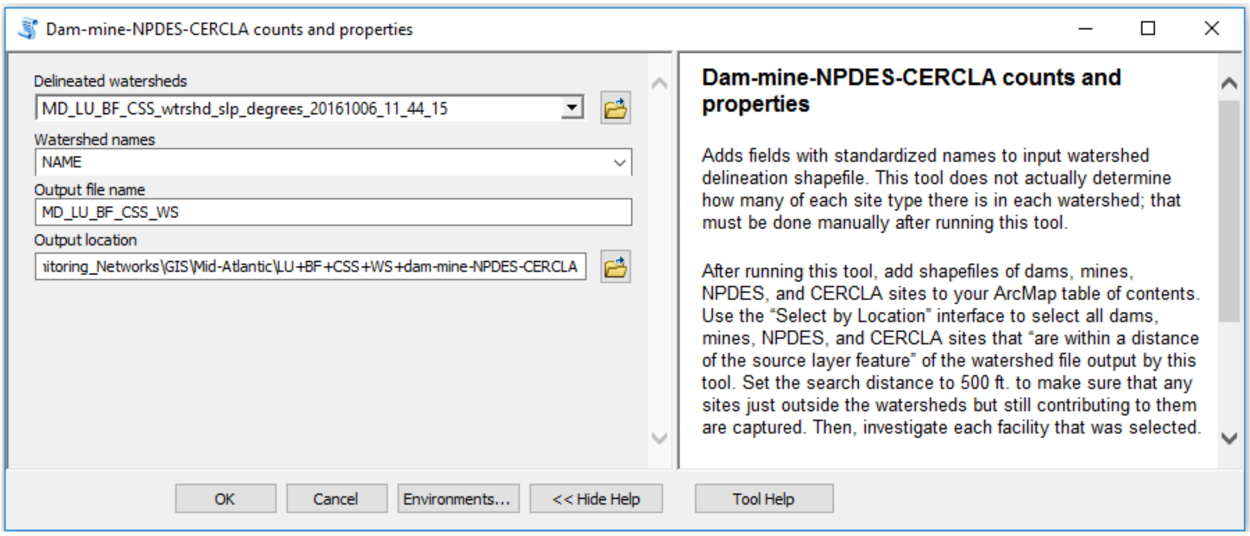


Figure 4-16. Dams, mines, NPDES, and CERCLA site search support tool interface.

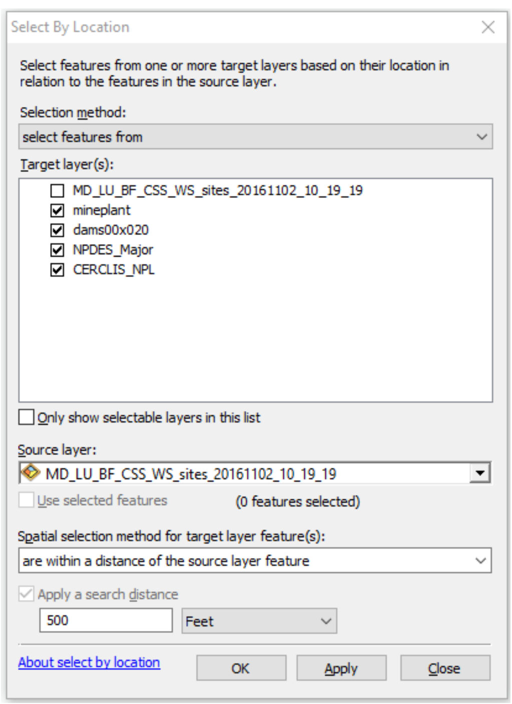


Figure 4-17. Selecting point source facilities within watersheds.

5. Whether this characterization process is done depends on the results of Step 4.

   a. If none are selected, use the “Field Calculator” to put 0s in the fields “dam_ct”, “mine_ct”, “NPDES_ct”, and “CERCLA_ct”. Then use the “Field Calculator” to put “N/A”s in the fields “dam_info”, “mine_info”, “NPDES_info”, and “CERCLAinfo”. It is important to note that there are no sites in these fields, so that it is clear that this was evaluated. Leaving these fields blank could cause uncertainty for subsequent users as to whether this step was completed. This concludes this characterization procedure for these sampling stations.

   b. If any dams, mines, NPDES, or CERLA points are selected, enter “Editor” mode for the watershed file output by this tool. Proceed to Step 6.

6. Zoom to each selected site in turn (i.e., those within the watersheds). Increment the appropriate count (“_ct”) field and note pertinent information in the appropriate notes (“_info”) field, such as distance from sampling station, size of lake behind dam, height of dam, type of NPDES facility, whether the facility is active, etc. (see Figure 4-18). This information is not meant to be an exhaustive profile of each site or its potential effects on water quality. It simply indicates which sites might significantly alter the watershed and should, therefore, be further investigated. If there are multiple sites of the same type within the same watershed, notes on each of them should go in the appropriate “_info” field.

7. Once all sites within the watersheds have been examined and added to the proper watershed attribute table fields, fill in any empty “_ct” cells with zero and any empty “_info” fields with “N/A”. This way, it is clear to future viewers that this step was done completely and all relevant sites were evaluated.

8. Save edits and exit “Editor” mode. This concludes this characterization procedure for these sampling stations.

dam_ct	dam_info	mine_ct	mine_info	npdes_ct	npdes_	CERCLA_ct	
0	N/A	0	N/A	0	N/A	0	N/A
0	N/A	0	N/A	0	N/A	0	N/A
0	N/A	0	N/A	0	N/A	0	N/A
0	N/A	0	N/A	0	N/A	1	Aerospace cor
0	N/A	0	N/A	0	N/A	0	N/A
0	N/A	0	N/A	0	N/A	0	N/A
0	N/A	0	N/A	0	N/A	1	Aerospace cor
0	N/A	0	N/A	0	N/A	0	N/A
1	Dam 0.75 km^2 5.5 km from sampling station on mainstem	1	Soil products mine 10.8 km from sampling station on tributary	0	N/A	0	N/A
0	N/A	0	N/A	0	N/A	0	N/A
1	Dam 0.32 km^2 1.5 km from sampling station on mainstem	0	N/A	0	N/A	0	N/A

Figure 4-18. Example site counts and descriptions. Watersheds without any of a site type have a zero for the count and N/A for the notes.

5. Technical support, updates, and known issues

5.1. Technical support

If you have questions about this guide or are having technical problems, e-mail Britta Bierwagen at bierwagen.britta@epa.gov. Please provide any relevant screenshots or outputs from ArcMap, as well as your input files.

5.2. Updates

Although tools may be added, updated, or revised over time (e.g., to add new features, fix bugs, or make compatible with new versions of ArcMap), no updates to this guide are currently anticipated. E-mail Britta Bierwagen to inquire about tool changes.

5.3. Known issues

There are currently no known issues with these tools that have not been described elsewhere in this guide. Please send any issues or suggestions you have. They will be compiled in the event that an updated guide is released.

6. Technical details of scripts

Below are technical outlines of the watershed characterization scripts for users who want more information on how these scripts work. The scripts were written May to October 2016 and tested in ArcMap 10.3.1. They were retested with ArcMap 10.4 and 10.5 in December 2017.

6.1. Land use composition

NOTE: requires the Spatial Analyst extension

1. The tool creates a subfolder within the output folder in which the processing happens (the "intermediate folder"). All intermediate files are created (some of which are deleted) in the intermediate folder. The final output delineation shapefile is the only file that is placed in the output directory the user specified. The intermediate folder name includes the final file name and a timestamp.

2. The tool checks the watershed delineation names for certain unusable characters. If any are found, the script returns an error and terminates.

3. The tool reprojects the input shapefiles to the same projection as the land use raster. That process will generally convert all *X*-*Y* units into meters.

4. The tool creates buffer polygons of two specified radial distances around each sampling station (1,000 and 5,000 m by default). If the user wants to get land use for more than two buffers, the user will have to run the tool multiple times, changing the script to different buffer distances each time.

5. The tool clips the station buffers to the boundaries of the corresponding watershed. The tool matches the names of the watersheds to the names of the buffers. Because the names of the buffers come from the name field selected for the sampling stations, the watershed names must have matching sampling station names (> buffer names).

6. The tool clips the input land use raster to the watershed delineations, the outer buffers clipped to watersheds, and the inner buffers clipped to watersheds. Each of these is a new raster, which is saved in the intermediate folder of the selected directory. These rasters have two fields added: the clipping extent (none or the inner or outer buffer distances) and the watershed name/station ID. These are used for transferring land use fractions to the output shapefile later in the script.

7. The tool adds a field to each clipped land use raster, which will store the fraction of each category of each land use. Then the tool calculates the fraction of each land use for each clipped raster based on the pixel count in that category and in the whole raster.

8. The tool copies the watershed delineation shapefile, assigns it the user's selected name, and adds one field for each possible land use-clipping extent combination (e.g., LU31_whole, LU42_5000). Note that this step adds all possible combinations based on the NLCD 2011 land use categories, so it may include land uses that are not encountered in the study area or within 1,000 or 5,000 m of any sampling stations. Then the tool iterates through each

clipped land use raster file and each land use in that raster to extract the land use fraction and copies it to the correct column of the output shapefile. Finally, it transfers the delineations with the land use fraction fields to the selected output folder.

6.2. Base flow

NOTE: requires the Spatial Analyst extension

1. The tool checks the watershed delineation names for certain unusable characters. If any are found, the script returns an error and ends.
2. The tool extracts the base flow value at each sampling station. By default, those values are put in a field in the sampling station shapefile called “RASTERVALU”.
3. The tool copies the watershed delineation shapefile, creates a new field in the watershed delineation shapefile called “BASE_FLOW”, and transfers the base flow from the sampling station to the new field in the delineation shapefile. This involves a nested “for” loop in which the tool matches each watershed with its sampling station and transfers the base flow values to the output watershed file.

6.3. Channel slope and sinuosity, pre-stream trace

NOTE: requires the Spatial Analyst extension

1. The tool creates a file geodatabase with a name that includes the state abbreviation and the time of creation.
2. The tool creates a feature class in that geodatabase with a name that includes the state abbreviation and the time of creation.
3. The tool projects the feature class to the projection of the flowline raster and adds a field in which the user will later note whether the stream trace segment is upstream or downstream of the sampling station.
4. The tool creates a 2,000 m buffer around each sampling station in the input shapefile. 2,000 m was chosen because it is several times larger than the usual trace length.
5. The tool clips the flowline raster to that 2,000 m buffer.
6. The tool converts the flowline raster within that 2,000 m buffer into polylines and saves it in the geodatabase as **flow_polylines_[STATEABBREV]_[YYYYMMDD_HH_MM_SS]**.

6.4. Channel slope and sinuosity, post-stream trace

NOTE: requires the 3D Analyst extension and ArcGIS Desktop Advanced license

1. The tool reprojects the manual stream traces and sampling points to the projection of the DEM. That way, the raster is not being reprojected, which can cause accuracy problems. The reprojected traces and sampling stations are used for the remaining steps. The final delineation shapefile from this tool is in the projection of the input traces.

2. The tool checks whether any of the stations do not have enough total trace length around them (upstream + downstream). ”Enough” is twice the user input trace length, which is the desired trace length in each direction. For example, if the user inputs a trace length of 1,000 m, each station must have a total of 2,000 m of stream trace (any combination of upstream and downstream). The tool counts how many stations do not have enough stream trace length and tells the user how many combined traces will be shorter than the specified amount. This is shown in the geoprocessing results window.

3. The tool checks whether any upstream and downstream traces are shorter than the desired user-input trace length. If any are too short, the tool reports how many are too short. Regardless of how many are too short, the tool will proceed. This step merely lets the user know if any traces are shorter than the input length and, therefore, will need to have extra trace length used in the other direction.

4. As the first step to trimming the traces to the desired length, the tool converts the traces into m-routes so that distance along them can be measured. The larger the m-value, the further from the sampling station.

5. The tool creates points at the specified distance from the sampling stations along each m-route trace. Whenever possible, the tool creates points at the trace length input by the user. For any traces that are shorter than that length, the tool creates a point at the end of the trace and adds the corresponding distance to the other trace at that station so that the total trace length compensates for insufficient trace length in one direction.

6. The tool splits the m-route stream traces where the aforementioned points were created. This effectively trims the stream traces to the desired distance. For any trace shorter than the desired trace length, the whole trace is included (i.e., not trimmed), while the other trace for that station is trimmed to a longer length to compensate for the shorter trace length.

7. The tool then combines the trimmed upstream and downstream traces (i.e., those within the specified distance of the stations, or the “inner” traces) into a single trace for each station. It does this by adding a field to each trace which is filled with the concatenated *X* and *Y* coordinates of the starting vertex. Only traces at the same station will have the same value. Because “inner” traces around each sampling station share the same starting *X* and *Y* coordinates (if they were snapped to the station, as required), inner traces starting at the same sampling station can then be dissolved into a single trace on the basis of their starting coordinates. There is now one trace per sampling station.

8. The tool duplicates the sampling point shapefile, adds a field for storing their *X* and *Y* coordinates in the same format as the stream traces’ starting *X* and *Y* coordinates, and then populates that field with the concatenated *X* and *Y* coordinates.

9. The tool then uses the concatenated *X* and *Y* coordinate field in the sampling station copy to join the station attributes to the traces. That way, each trace can be identified by its waterbody or station ID.

10. The tool calculates trace sinuosity using planar distance. The formula is channel length/valley length. Channel length is the planar length of the trace. Valley length is the straight line distance between the trace end points, which is calculated using the standard two dimensional distance formula (sqrt[$(X1-X2)^2 + (Y1-Y2)^2$]) because the distances involved are fairly small. Sinuosity and precursor values are stored in the trace feature class.

11. The tool calculates channel slope. Channel slope = change in elevation ÷ trace length. To do this, the traces are converted to z-enabled lines using the supplied DEM, and the starting and ending elevations are stored in new fields of the trace. Note that the starting and ending elevations are based on bilinear interpolation, so they won't exactly match the values of the DEM pixels underneath them but rather should be an interpolation of nearby pixels. With the starting and ending elevations in the DEM's vertical units in hand, the script calculates the starting and ending elevations in meters and uses those values for slope because the length of the traces is provided in meters.

12. The tool copies the input delineation shapefile into the user-specified directory, joins the stream trace table to it, and copies the trace length, the sinuosity, and slope to the delineation shapefile. The trace length is copied to make it easy for users to check whether all traces were the correct length (i.e., none should be longer or shorter than twice the input trace length).

13. The tool deletes all the intermediate files that were created inside the geodatabase. If the user wants to keep those files for error checking, debugging, or other uses, they can be disabled by a comment code.

6.5. Watershed slope

NOTE: requires the Spatial Analyst extension

1. The tool reprojects the watersheds to the projection of the DEM. That way, the raster is not being reprojected, which can lead to accuracy problems. The reprojected watersheds are used for slope calculations in each watershed but the final output shapefile from this tool is in the projection of the input watershed shapefile.

2. The tool calculates slope (in degrees) for the entire DEM, creating a slope raster for the study area.

3. The tool copies the watershed delineation shapefile to the output folder and adds five empty fields (maximum, minimum, mean, range, and standard deviation of slope).

4. The tool creates layers out of the reprojected watersheds and the final output watersheds. It creates layers from them so they can be individually processed in the next step.

5. The tool iterates through each feature in the reprojected watersheds layer and uses Zonal Statistics as Table to get watershed slope parameters for each watershed individually. These are stored in a one-row table, which is joined to the final output delineation layer. The slope values are copied to the output shapefile layer, then the one-row table is deleted. The tool iterates through the watersheds individually rather than doing Zonal Statistics on all of them

at once because there are complications with using Zonal Statistics on nested watersheds. Processing each watershed individually avoids the problems with nested watersheds.

6. The tool optionally deletes the intermediate files. Because the deletions occur at the end of the script in sequential lines, they can easily be prevented by placing a comment code (i.e., "#") at the beginning of each line.

6.6. Dams, mines, NPDES, and CERCLA site preprocessing

1. The tool copies the watershed delineation shapefile from the input location to the output location and gives it the user-specified name.
2. The tool adds eight fields: four to store the counts of the dams, mines, NPDES, and CERCLA sites, and four to store notes about each of them. The former fields are of type SHORT integer and the latter are of type TEXT (250 characters maximum).

SC
IEN
CE

United States
Environmental Protection
Agency

PRESORTED STANDARD
POSTAGE & FEES PAID
EPA
PERMIT NO. G-35

Office of Research and Development (8101R)
Washington, DC 20460

Official Business
Penalty for Private Use
$300