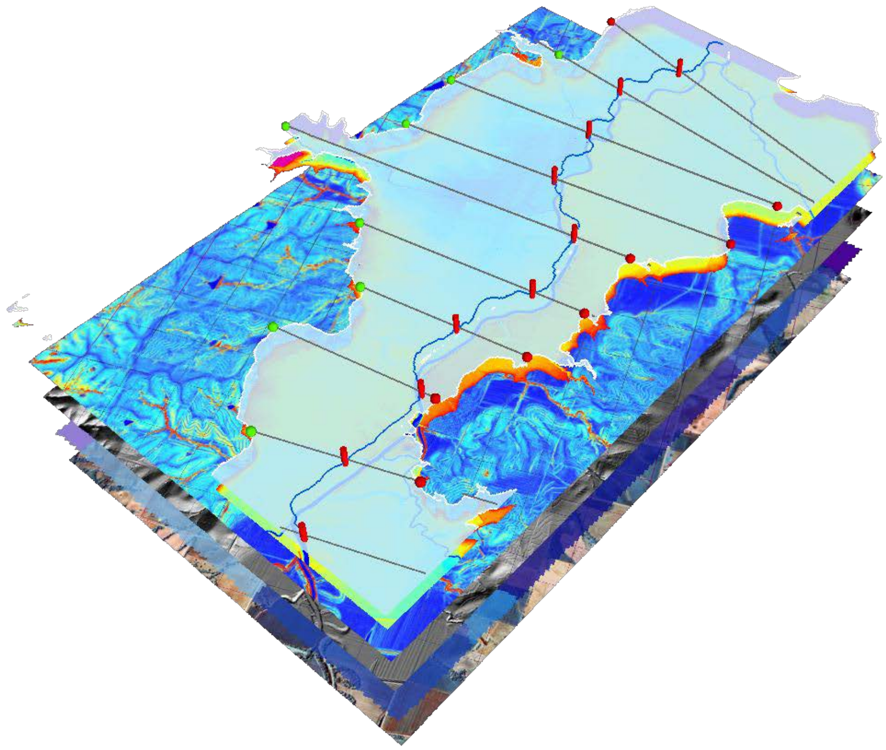

HYDROGEOMORPHIC ANALYSIS FOR FUNCTIONAL PROCESS ZONE DELINEATION

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Table of Contents

1. Introduction

The functional process zone (FPZ) classification procedure is characterized by statistical self-emergence of groups as opposed to investigator assignment of river sections to predetermined groups based on physical or biological criteria *sensu* the Rosgen Method (Rosgen 1994). For self-emergent properties of FPZs to be expressed, the stream network must first be divided into uniform sample segments based on user-defined stream lengths. This allows the hydrogeomorphic character of each segment to be assessed independently and grouped with other segments based on similarity (thereby defining different FPZs). The hydrogeomorphic variables used in the classification are measured at scales that bracket the FPZ scale (the watershed, river valley, and river channel scales) (Table 1). These variables embody fundamental geologic, climatic, and topographic characteristics of riverine landscapes, they can be quantified using freely available geospatial datasets, and are thought to be an ideal minimum set of variables that could identify distinct river valley scale differences within a watershed. Automated GIS-based processes were designed for ArcGIS® and FLDPLN that enable rapid collection and processing of GIS data sources and geomorphic variable extraction. A general outline of the process and data products inputted or exported from individual process steps is given in Figure 2. Each of these process steps and instructions for formatting data layers, generating data layers with Arch Hydro and FLDPLN, and conducting geospatial analysis with RESonate are detailed in later sections of this manual. For additional background on underlying theory, classification approaches, development of RESonate, and potential applications of this process see the following publications: Thorp et al. 2006, Thorp et al. 2008, Williams et al. 2013, and Thorp et al. 2010.

Scale	Variable	Abbreviation
	Mean annual precipitation	PRE
Catchment	Geology	GEO
	Elevation	ELE
	Valley width	VW
	Valley floor width	VFW
River Valley	Ratio of valley width to valley floor width	RAT
	Left valley side slope	LVS
	Right valley slope	RVS
	Down valley slope	DVS
	Channel belt width	CBW
River Channel	Channel belt sinuosity	CBS
	River channel sinuosity	RCS
	Channel planform	PLN

Table 1. Spatial scale and hydrogeomorphic variables used in the FPZ classification procedure.

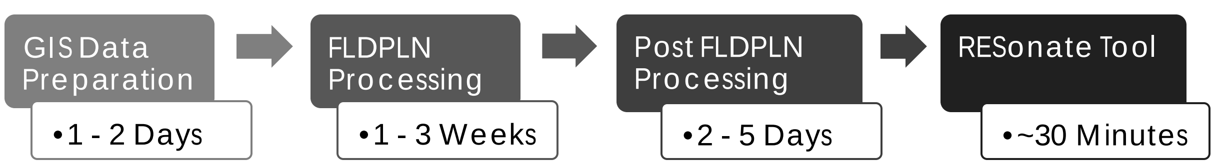


Figure 1. Estimated processing time associated with the hydrogeomorphic analysis workflow of one river network. Users new to RESonate procedures may require additional time.

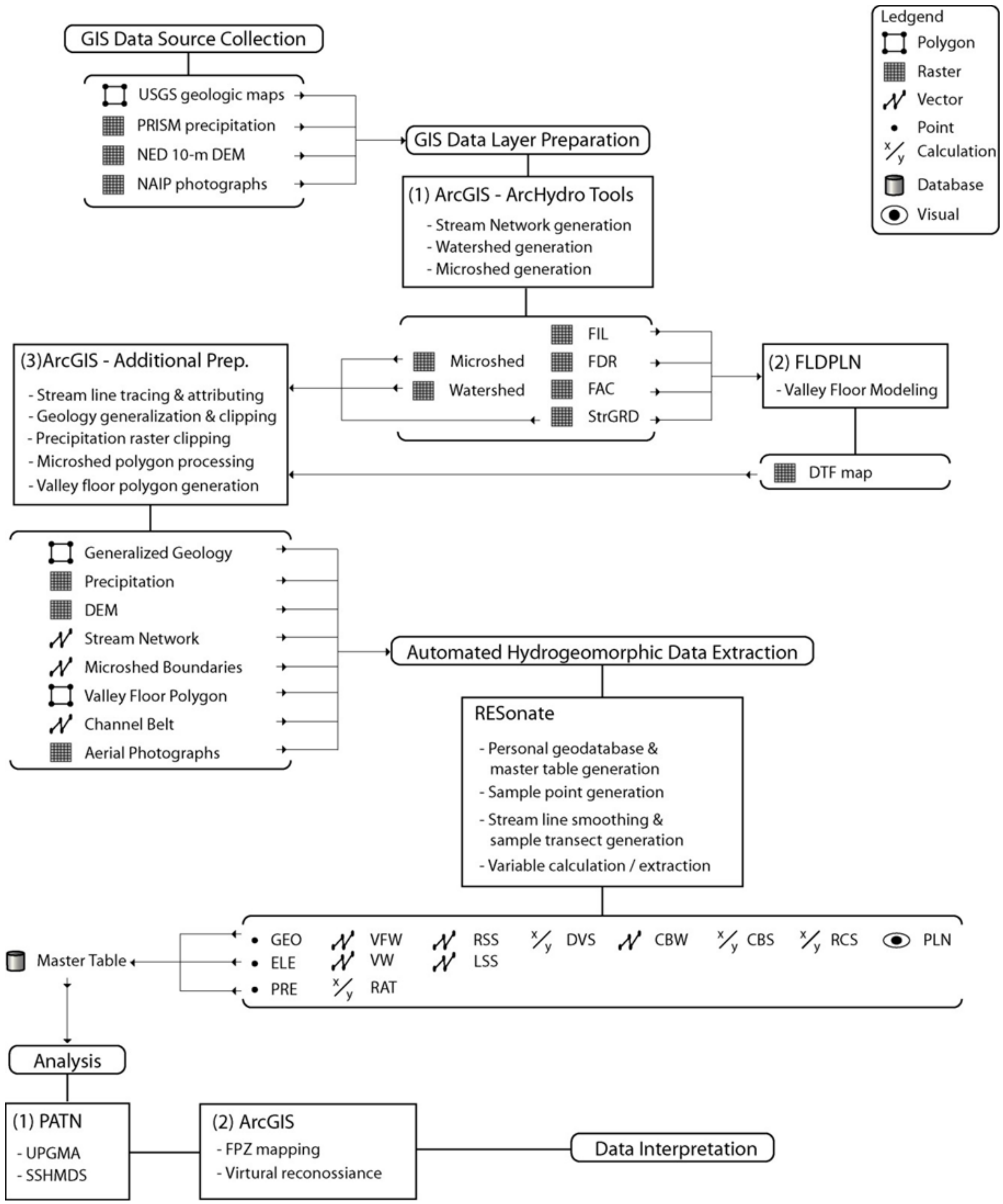


Figure 2. A generalized flow chart summarizing major steps in functional process classification, data inputs used and/or data products produced in each step, and their respective formats.

2. Hardware and Software

2.1 Recommended system specifications

Large data files and intensive data processing are required for FPZ delineation and one or more powerful desktop computers are needed to complete the process in a timely manner. Special consideration should be given to the amount of memory, processer speed, number of processing cores, hard drive capacity, and hard drive transfer rate when selecting computers. In order to avoid processing bottle necks, delineation tasks should be spread across multiple computers or contained in a single high-power workstation with multiple multi-core processors and multiple hard drives. A number of raster modeling procedures are used that require extended periods of processing time where large files are frequently read from and written to a hard drive. We have found that it is much more time and resource efficient to direct the models to access a secondary storage hard drive instead of the main system drive containing the OS. This prevents continuous model read/writes from interfering with other FPZ delineation processes and basic Windows operations.

Given the extremely large size of DEM rasters users may benefit from non-standard hard drive configurations that boost data transfer rate. A redundant array of inexpensive drives (RAID) array consisting of 2 or more high speed standard or solid state hard drives in RAID 0 configuration can decrease overall processing time by increasing the rate of read/write operations. Because failure of any one drive in a RAID 0 will result in total array failure and complete data loss, users should invest in a reliable backup solution such as an external hard drive or server.

This process has been evaluated on a variety of computers ranging from low-end desktops to high performance server workstations. The minimum and ideal system specifications are listed below.

Minimum System Specifications:

Operating System: Windows XP 64 or 32-bit
Processor: 2GHz quad-core processor **Memory:** 4 GB
Primary Hard Drive: 250 GB, 7200 RPM, 32 MB cache, non-RAID
Secondary Hard Drive: 250 GB, 7200 RPM, 32 MB cache, non-RAID

Ideal System Specifications:

Operating System: Windows XP 64-bit, Windows Vista 64-bit, or Windows 7 64-bit
Processor: (2) 2.33 GHz Xeon quad-core processors
Memory: 8 GB
Primary Hard Drive: (3) 250 GB, 7200 RPM, 32 MB cache, RAID 0
Secondary Hard Drive: 250 GB, 7200 RPM, 32 MB cache, non-RAID

2.2 Software requirements

GIS data layers required for analysis are prepared using a combination of available tools in ArcGIS 10+®. Layer generation requires Spatial Analyst, 3D Analyst, and Arc Hydro extensions. Additional data layers are generated with the FLDPLN flood model and supporting functions written for MATLAB® (Kastens, 2008), which are discussed in later sections of this manual. The download links to Arc Hydro, RESonate, and FLDPLN are listed below.

ArcHydro Tools / App Framework
The ArcHydro Tool can be downloaded from multiple sources and continues to be revised. The most current version can be downloaded from:
http://downloads.esri.com/ArcHydro/ArcHydro/Setup/10.3/10.3.0.8/ArcHydroTools10.3/

These tools are also accessible under the **Hydrology** tab of the **Spatial Analyst** toolbox.

RESonate Toolbox
http://www.aquaticecolab.res.ku.edu/software/

FLDPLN – Valley Floor Mapper V1.0
http://www.aquaticecolab.res.ku.edu/software/

Useful Statistical software packages

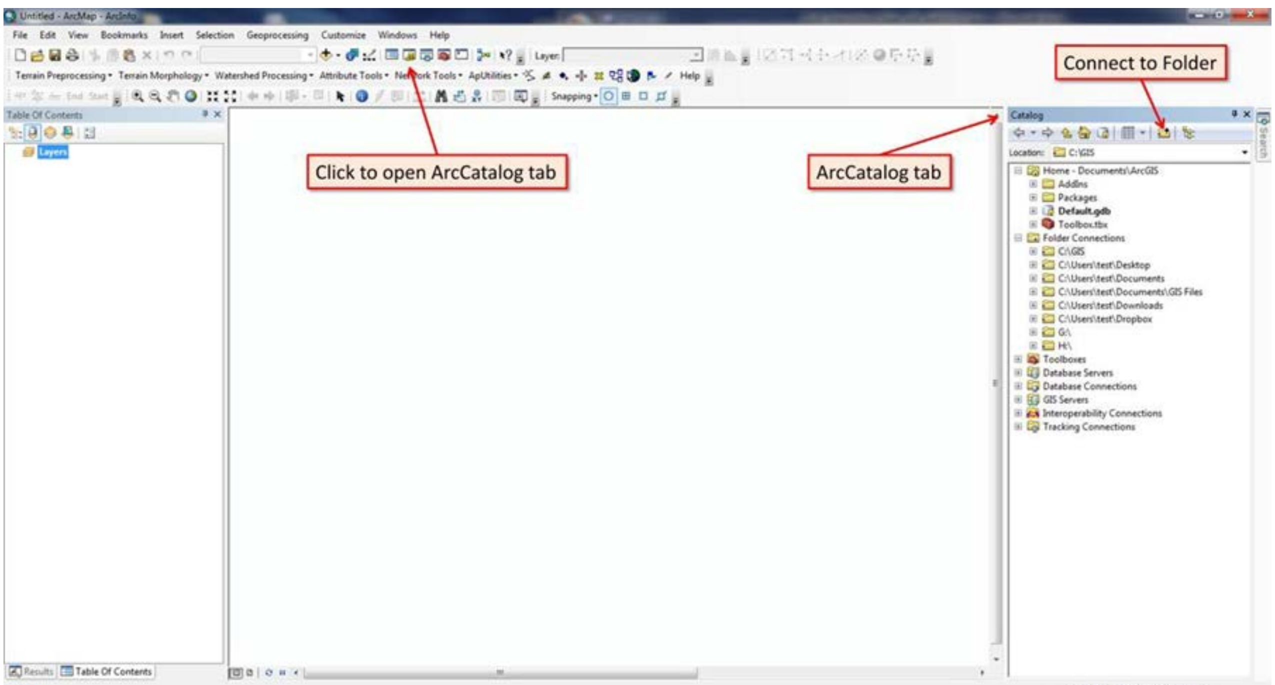
R Studio
MINITAB
PRIMER
PATN 3.11

3. Initial Source Data Collection and Organization

3.1 Data storage and organization

Many data products will be generated during the course of FPZ delineation so it is important to establish a highly organized series of folders to keep track of intermediate data layers, final data layers, and analysis documentation. We suggest that the following organizational scheme be used to keep track of all data associated with delineation.

1) ▶ Open ArcMap from the Start menu. In the **ArcCatalog** tab, click **Connect to Folder** and create a new connection to a folder in the directory where all geospatial data used in the procedure will be stored. Be sure that the HD selected has plenty of free space (~200 GB). (**Note**: If the ArcCatalog tab is not active in ArcMap, go to Windows on the Menu bar then click on Catalog.)

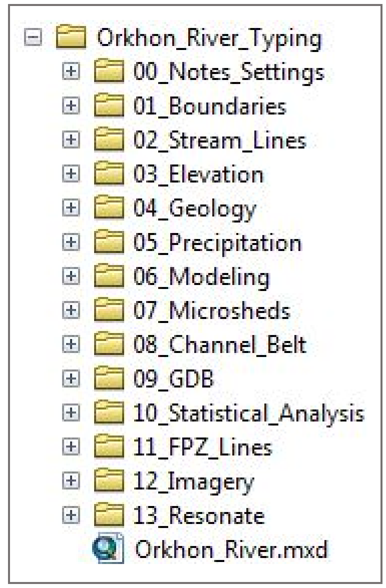


2) ▶ Name the folder **"X"_River_Typing** where **"X"** is the name of the watershed to be analyzed.

Note: The use of underscores "_" instead of spaces in file naming conventions is critical to ensuring that file paths are recognized by RESonate and ArcGIS geoprocessing tools. While folders may be cited in this manual without an underscore for readability, it is **required** to use such characters in the users' folder hierarchy.

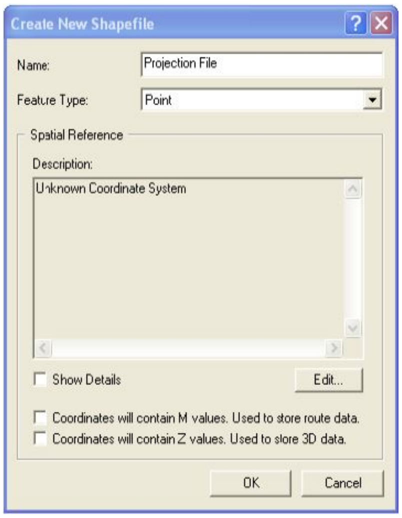
3) ▶ Within the **“X”_River_Typing** folder, create the following folder hierarchy with the numbers and names outlined below:

- “X”_River_Typing (Root Folder)
- 00_NotesandSettings
  - 01_Projection File
  - 02_Process Notes and Settings
- 01_Boundaries
  - 01_Watershed
  - 02_Political
- 02_StreamLines
  - 01_NHD Stream Lines
  - 02_ArcHydro Stream Lines
  - 03_Final Stream Lines
- 03_Elevation
  - 01_NED Data
    - 01_NED_Projected
  - 02_Merge
  - 03_Analysis DEM
- 04_Geology
  - 01_Original Geology
  - 02_Generalized Geology
- 05_Precipitation
  - 01_PRISM Data
  - 02_Recalculated PRISM
  - 03_Clipped PRISM
- 06_Modeling
  - 01_ArcHydro
  - 02_FLDPLN
    - 01_FLDPLN Files
    - 02_Valley Floor Extent
- 07_Microsheds
- 08_ChannelBelt
  - 01_GeneralizedStreams
  - 02_CBLines
- 09_GDB
- 10_StatisticalAnalysis
- 11_FPZLines
  - 01_FPZLines
  - 02_Maps
- 12_Imagery
- 13_Resonate
- “X”_River.mxd (ArcMap Document)

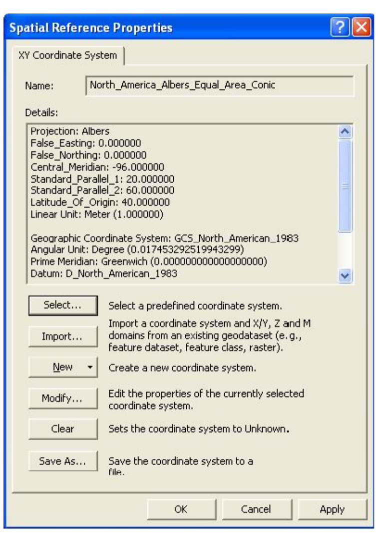


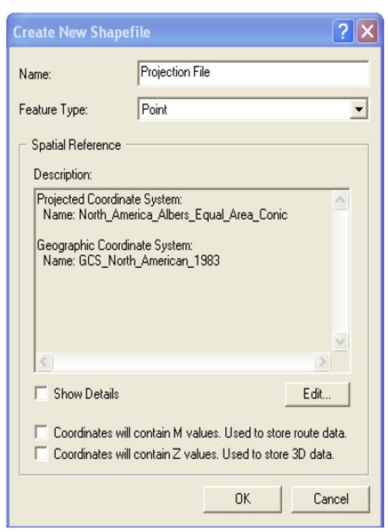
4) ▶ Determine which map projection will be used for all data layers in the analysis. It is important that all data layers share a common projection to prevent misalignments and inaccurate results. We recommend the **North American Albers Equal Area Conic** as a good general purpose projection when working with multiple watersheds distributed throughout North America.

5) ▶ Create a blank shapefile in the **"X" River Typing » 00 Notes and Settings » 01 Projection File** folder by right clicking on the folder name and selecting **New » Shapefile** from the pop out menus. Name it **Projection File** and set **Feature Type** to any type you wish.



6) ▶ Click the **Edit** button in the **Create New Shapefile** window to open the **Spatial Reference Properties** window. Next, click the **Select** button to open the **Coordinate System** dialog box and navigate to the Albers projection by selecting the following file folders: **Projected Coordinate Systems » Continental » North America » North American Albers Equal Area Conic.prj**. Click the **Add** button to add the projection and then click **OK.**





7) ▶ The projection shapefile will serve as a shortcut for future operations. Its projection can be used when adding a projection to or reprojecting other files. Simply click **Import** from the **Spatial Reference Properties** window of the desired file and navigate to the projection file in the folder hierarchy and click **Add**. Always referencing a single file will prevent users from accidently selecting a different projection.

8) ▶ Create a new Microsoft Word or .txt file named **"X" Notes and Settings** in the **"X" River Typing » 00 Notes and Settings » 02 Process Notes/Settings** folder. This file will contain all notes related to the river typing process and should include a separate page devoted to documenting all system settings. System settings are values or parameters selected by the user during the analysis and are needed in order reproduce model and analysis results. **This file must be updated if processes are rerun with different parameters!**

Note: The RESonate Tool will automatically record tool input parameters to a text file called **StreamName_RESdatalayers.txt**. It would be good practice to save a copy of the file here.

3.2 Primary data source collection and initial preparation

3.2.1 Watershed and political boundaries

The first step in source data collection is to acquire watershed and political boundaries. While these files will not be used in the analysis, they are useful visual references that can facilitate data collection and reporting. A much more accurate watershed boundary will be generated in a later step once the appropriate elevation data has been obtained. We recommend using the **USDA Geospatial Data Gateway** (https://gdg.sc.egov.usda.gov/) to acquire county and state level data. Many states also make this type of data available through their own geospatial database websites.

Watershed Boundaries

1) ▶ Go to https://gdg.sc.egov.usda.gov/ and click the **Get Data** button on the upper right side of the webpage.

2) ▶ Users can choose whether to download data by counties, states, place, latitude/longitude, or through a custom window under the **Where** tab in the center of the page. Click **HERE** and then **Order by State** to select state level data.

3) ▶ Select the state containing the study watershed from the **Select entire state for order** drop down menu (**Note:** multiple states may need to be downloaded to cover the entire watershed area).

4) ▶ Select the 8 Digit Watershed Boundary Dataset under Hydrologic Units (8 Digit HUC), NRCS States by State and Federal, State, Tribal Land Ownership under Government Units (PRISM and Geology can also be selected).

5) ▶ Click **Continue** at the bottom of the page.

6) ▶ Under the **How** tab, specify **Format** as **ESRI Shape** (to minimize the number of merge operations later), **Projection** as **Geographic NAD83** (or the projection closest to your selected projection), and **Delivery** as **DownLoad**. Click **Continue**.

7) ▶ Provide the required contact information in the **Who** tab and click **Continue**. Review the data request and click **Place Order** (on the left) when finished. A link to the data will be sent to the Email address you provided. Right click on the link and click **Save As** to save the .zip file to the **"X" River Typing » 01 Boundaries » 01 Watershed** folder. Unzip the shapefile and add it to a new map document in ArcMap. You can also select **Check Order**, enter your email address and press **Go** to see all of your orders and their progress.

8) ▶ Multiple watershed polygon files will have to be merged if the study watershed spans multiple states. Click the **Tool Box** button on the **Standard** tool bar in ArcMap to open the **Tool Box** window. Select **Data Management Tools » Merge** tool. Add the separate polygon files using the Input Datasets drop down menu. Set the Output Dataset to **"X" River Typing » 01 Boundaries » 01 Watershed** and name the file **"X"_Huc8_Merge**. Click **OK** to start.

9) ▶ Right click on **"X"_Huc8_Merge** in the **Table of Contents** window and select **Open Attribute Table**. There should be a field named **Basins.** Select the subwatersheds that comprise the study watershed by selecting **Select by Attributes** from the **Table Options** pull down menu at the top left corner of the table. **Note:** Some HUC8 designations have no BASIN attribute data, but also do not have names that correspond directly to the desired study stream. In these cases the best solution is to check published basin boundaries, and then manually select the desired stream basin extent.

10) ▶ In the **Select by Attributes** window, set **Method** to **Create new Selection**, double click on Basin to add it to the command window, and select or input the "=" sign. Highlight "BASIN" in the Fields window and click Get Unique Values. Double click on the desired basin to add it to the command window and click Apply and Close. If there is no "BASIN" attribute, select by "STREAMNAME" following the same process. **Note:** If the entire study basin is not selected using the "STREAMNAME" attribute, manually select subwatersheds and add them to the selection.

11) ▶ When the desired basin extent is selected, right click on **"X"_Huc8_Merge** and select Selection » **Create Layer from Selected Features** from the menu.

12) ▶ Check the outline of the new **"X"_Huc8_Merge selection** layer against published watershed boundaries (*e.g.* Benke and Cushing 2005, 2010) to ensure that the selection represents a complete watershed.

13) ▶ Right click on **"X"_Huc8_Merge selection** in the **Table of Contents** window and select **Data » Export** from the menu. In the **Export Data** window, set **Export** to **All Features**, **Coordinate System** to **this layer's source data**, and **Output shapefile to Output Dataset** to **"X" River Typing » 01 Boundaries » 01 Watershed** and name the file **"X"_Watershed_subs**.

14) ▶ Create a copy of **"X"_Watershed_subs** named **"X"_Watershed** and add it to ArcMap. Select **Editor » Start Editing** from the **Editor** tool bar pull down menu. Select the **"X"_Watershed** from the **Create Features** panel.

15) ▶ Right click on **"X"_Watershed** in the **Table of Contents** window and select **Open Attribute Table**. Select all records in the attribute table then select **Editor » Merge** from the Editor tool bar drop down menu. Click **OK** in the **Merge** window to start.

16) ▶ If the polygon is complete and error free, select **Editor » Save Edits » Stop Editing**.

17) ▶ Reproject **“X”_Watershed_subs** and **“X”_Watershed** files into the desired projection (e.g. Albers) by selecting **Data Management » Projections and Transformations » Feature » Batch Project** from the **Tool Box** window. Add the files as the **Input Feature Class or Dataset**, set the **Output Workspace** to the **"X" River Typing » 01 Boundaries » 01 Watershed** folder, and set the **Output Coordinate System** by importing the **Projection File’s** projection. Click **OK** to Start.

<u>Political Boundaries</u>

State and county boundaries are also available through the USGS Geospatial Data Gateway (https://gdg.sc.egov.usda.gov/) and from State GIS websites. Download the appropriate state and county boundaries, select out the portions within the study area and reproject as necessary. Save the outputs to **"X" River Typing » 01 Boundaries » 02 Political.** See previous section for general instructions on downloading, manipulating, and reprojecting data.

3.2.2 Stream line data

Stream lines used in the analysis will be generated by a series of modeling procedures in later steps. Model derived networks are essential because their lines directly correspond to the DEM used in analysis. Stream line vectors from other sources could potentially be used; however, non-conformity with the analysis DEM could contribute to significant measurement error. Pre-generated stream lines, such as those compiled for the National Hydrography Dataset Plus program (NHDPlus), often contain stream name attributes and provide useful reference. Also, stream name attributes can be quickly transferred to corresponding modeled stream lines via the Attribute Transfer tool.

1) ▶ Go to http://www.horizon-systems.com/nhdplus/ and click on the **NHDPlus Data** link in the navigation column on the far left of the page.

2) ▶ Select the desired **hydrologic data region** from the national map to navigate to the data portal for that region.

3) ▶ Use the map to determine which sub-watersheds (product units) are needed.

4) ▶ Once sub-watersheds have been selected, find the **National Hydrography Dataset** data link for each. Each NHD file needs to be saved to a unique subfolder within the **"X" River Typing » 02 Stream Lines » 01 NHD Stream Lines** directory. Name each subfolder "**NHDPlus Region X,x**" (where X = Region # and x = unit letter). Right click and select Save Target As to save the file to the corresponding folder. Uncompress each file within its folder and delete the original compressed file.

5) ►Add the downloaded NHDPlus data and the **"X"_Watershed** boundary to a new ArcMap and confirm that the NHD data covers the entire watershed.

6) ► Open the attribute table of each NHD flowline file to ensure that stream lines have the proper name attributes (see the **GNIS** field).

7) ► Remove any unnamed lines (extraneous data) by selecting **Editor » Start Editing**. In the NHD flowline attribute table select **Options » Select By Attributes.** Double click on **GNIS** to add it to the command window, select or input the "=" sign, and the **""** signs to represent no value. Click **Apply** and **Close**. Right on a selected field and select **Delete**. Click **Save edits** and **Stop editing**.

8) ► Clip the NHD flowlines to the watershed boundary by selecting **Analysis Tools » Extract » Clip** from ArcToolbox**.** Select NHD flowlines as the input feature and "X" Watershed as the clip feature. Place the output class feature in **"X" River Typing » 02 Stream Lines » 01 NHD Flowlines** and name it **"X"_NHD_Flowlines**. Delete all other files in the directory.

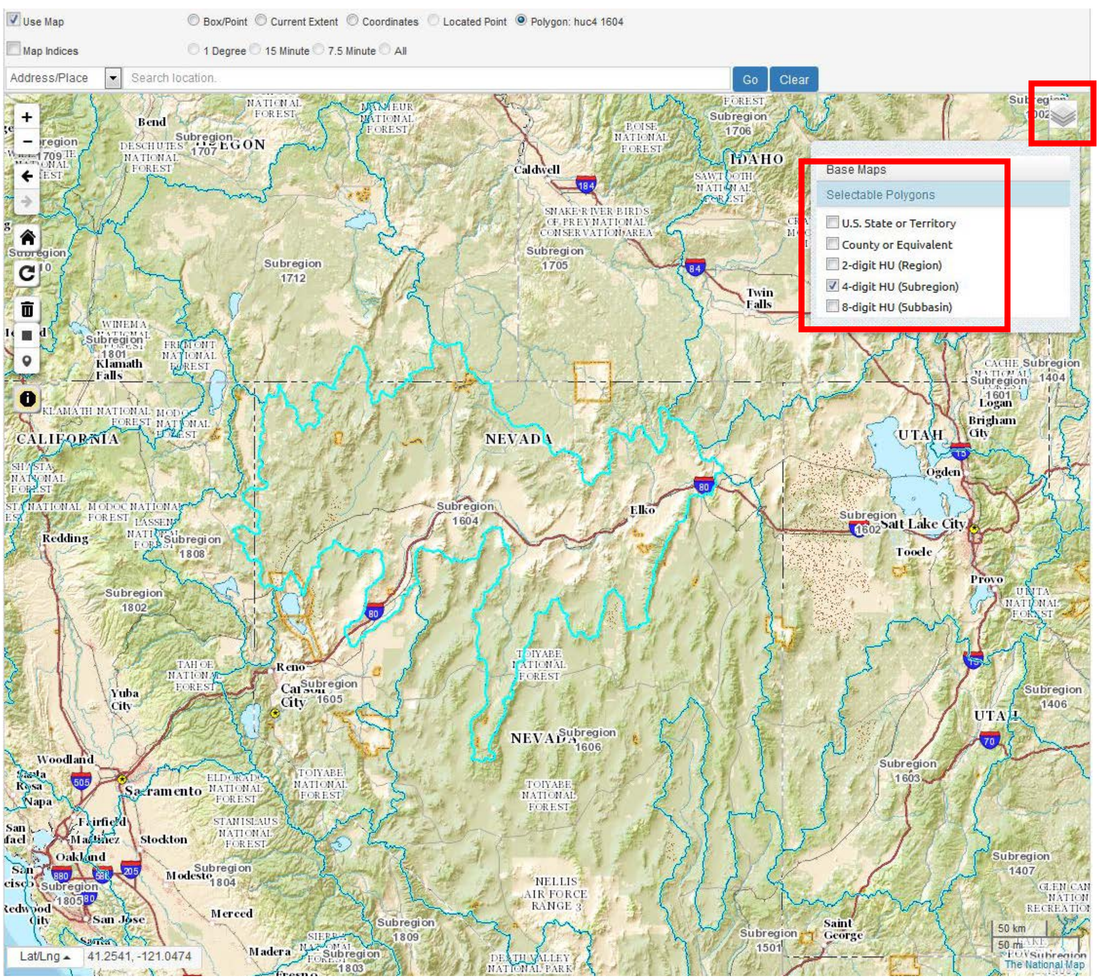
9) ▶ Reproject **"X"_NHD_Flowlines** into the desired map projection.

3.2.3 Elevation Data

Most hydrogeomorphic variables will be derived from elevation data, and the use of high quality digital elevation models (DEMs) is imperative. The **10-m DEM** maintained by the **National Elevation Dataset (NED)** is the most extensive, relatively high-resolution data available for the entire U.S., excluding Alaska. The 10-m NED data can be obtained free of charge from a variety of sources. The USGS seamless data warehouse (http://nationalmap.gov/elevation.html) provides data at multiple spatial scales, and has the ability to search for NED tiles at the HUC8 level. The USDA Geospatial Data Gateway (http://datagateway.nrcs.usda.gov/) also provides access to NED tiles. Both of these sources primarily provide and deliver data for small AOI tiles, such as counties, that require a great deal of search, download, and processing time.

Downloading DEM Data

1) ▶ Go to http://viewer.nationalmap.gov/basic/ and click on the layers icon in the top right corner. Select **4-digit HU (Subregion)** or **8-digit HU (Subbasin)** and select the regions or basins that encompass the study watershed.

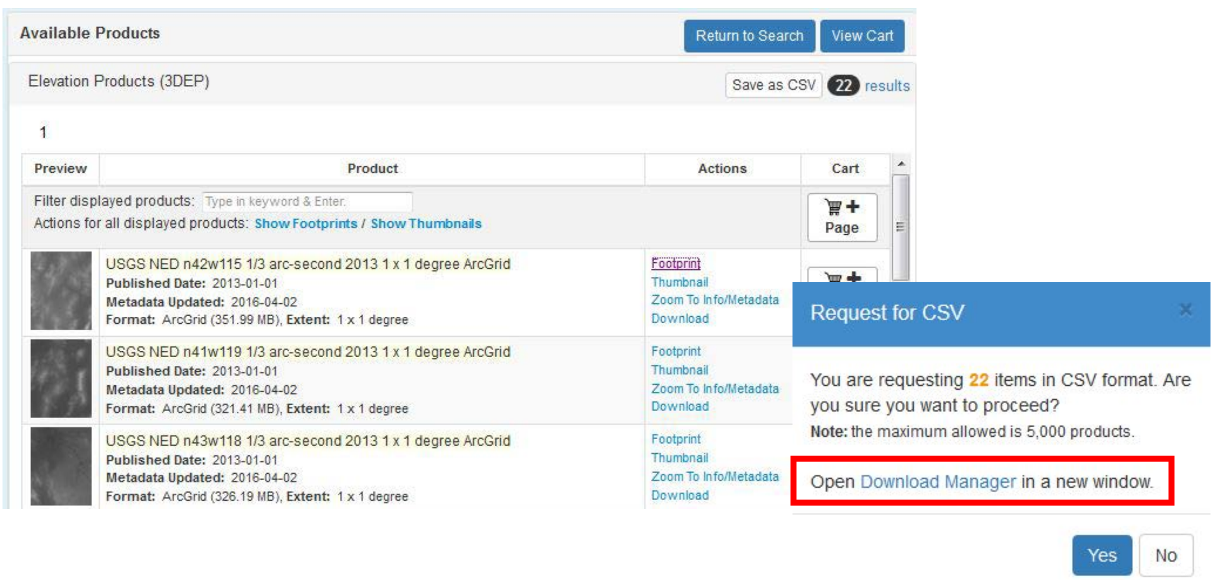


2) ▶ Under **Data** select **Elevation Products (30EP)** and **1/3 arc-second DEM**. Select **ArcGrid** as the File Format. Click **Find Products**.

Note: We recommend working with rasters in GRID format when possible.

3) ▶ Ensure that the tiles overlap with the study area using the **Footprint** overlay. If there are a large number of tiles outside of the study area, refine your search. Once you are ready to download the DEM tiles, select **Save as CSV**. A **Request for CSV** message should appear. If you have not already downloaded the bulk file download manager, open **Download Manager** and download the latest version. Then select **Yes** in the CSV Request box to start the DEM tile download.

USGS Download Manager: http://viewer.nationalmap.gov/apps/download_manager/



Processing DEM Data

1) ▶ Downloaded NED tiles for the study watershed should be saved to the **"X" River Typing » 03 Elevation » 01 NED Data** folder. If data was acquired via bulk data delivery, copy and paste any relevant NED tiles to the above directory.

2) ▶ Open ArcMap and add all NED tiles in the **"X" River Typing » 03 Elevation » 01 NED Data** folder into the map window.

3) ▶ In ArcToolbox, Select **Data Management Tools » Raster » Raster Dataset » Mosaic to New Raster** to open the Mosaic to New Raster tool.

4) ▶ Add raster layers to the input raster dialog. **Note**: The tool may crash if given too many large DEM tiles at once. A series of mosaic operations may be required to create seamless DEMs of large watersheds.

5) ▶ Set the output location to **"X" River Typing » 03 Elevation » 01 Merge**.

6) ▶ Input a unique name for each mosaic (do not specify an extension after the name). ESRI GRID format is used when the extension is left blank. Name the final mosaic **"X"_DEM_M**.

7) ▶ Set **Pixel Type** to 32bit Float and **Number of Bands** to 1. Use defaults for all other fields and select **OK**.

8) ▶ Reproject final mosaiced raster into the desired map projection.

9) ▶ Clip raster to watershed boundary. Save to **"X" River Typing » 03 Elevation » 01 Merge** as **"X"_DEM_C**.

3.2.4 Geologic data

Geologic information can reveal whether a section of river flows through alluvium, bed-rock, or non-alluvial sediments such as aeolian soils. This information can be obtained from state geologic maps digitized by the U.S. Geological Survey (USGS); however, differences in map scale and classification schemes among states can hamper efforts to generate uniform geologic data layers for watersheds spanning multiple states. To overcome this limitation, a highly generalized geologic map needs to be generated for the study watershed by merging existing geologic attributes of polygons into coarse categories (e.g., alluvial, non-alluvial, bedrock, or reservoir).

1) ► Go to http://mrdata.usgs.gov/. Find the heading marked Geological data and click on Geologic maps of the US states.

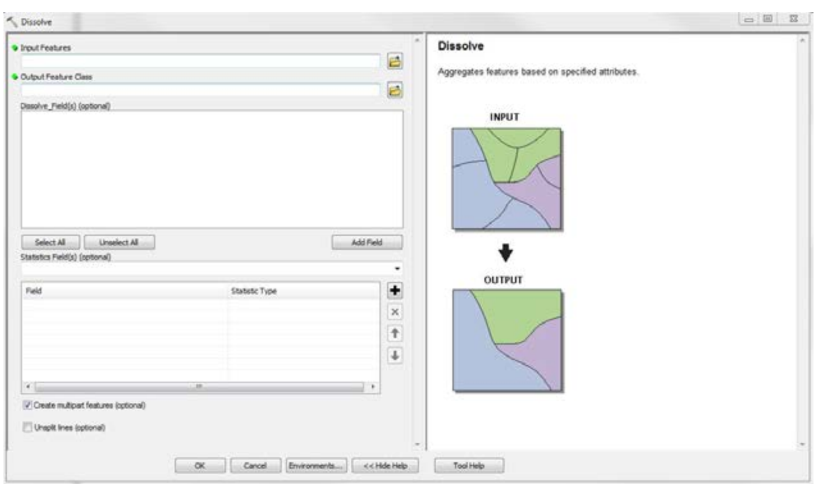
2) ► Select the desired state from the directory.

3) ► Under the download heading right click on the **Geologic units** file link and save as **"(State name)_Geol_Unit"** in the **"X" River Typing » 04 Geology » 01 Original Geology** folder.

4) ► Clip the geologic data to the watershed boundary and save the resulting file as **"(State name) geologic units clip"** in the same folder.

5) ► Reproject **"State name"_geologic_units_clip** into the desired map projection.

6) ► Select **Data Management Tools » Generalization » Dissolve** from Arc Toolbox. Set **Input Features** as **"State name"_geologic_units_clip** and the **Output Feature Class** as **"State name"_generalized_geology** in the **"X" River Typing » 04 Geology » 02 Generalized Geology** folder. Next, **set Dissolve Field(s)** to the field that contains the primary lithology, click **Create multipart features**, and click **OK** to run.



7) ► Start editing the newly created generalized geology layer. Open attribute table and reclassify the primary lithology into the coarse categories chosen for the study.

3.2.5 Precipitation data

Precipitation data can be obtained through a variety of sources. Users can gather raw and often very long-term data from weather stations throughout the U.S. via the National Climatic Data Center (NCDC). Raw precipitation data require a great deal of processing to determine long-term means and interpolate values between monitoring stations. Pre-processed, GIS-ready databases are available from a number of sources. Thirty-year mean annual precipitation databases for the entire U.S. are available from the NCDC and PRISM Climate Group. We recommend the raster-based PRISM 30-yr (1981- 2010) mean annual precipitation database due to PRISM's ability to accurately reproduce climatic conditions by accounting for the effects of elevation and coastal areas on precipitation (Daly *et al*., 1997; Daly *et al*., 2000).

A helpful resource for editing PRISM data can be found at:
https://coast.noaa.gov/digitalcoast/_/pdf/Guidance_for_Preprocessing_PRISM_Data.pdf

1) ▶ Go to http://www.prism.oregonstate.edu/normals/ to download the PRISM 30yr mean annual precipitation (800m resolution) raster for the contiguous U.S.

2) ▶ Select the **800m** spatial resolution (or 4km depending on need); **precipitation**, and **annual values**. **Click** on the **Download Data (.bil)** link and save the file to **"X" River Typing » 04 Precipitation » 01 PRISM Data**.

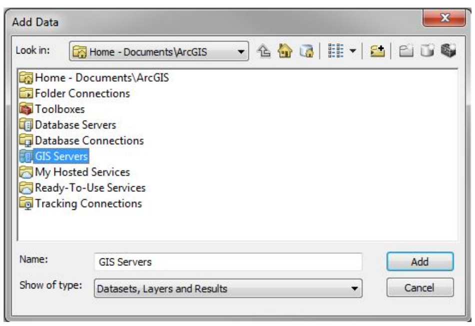
Note: If the PRISM data is in ASCII or Text format: convert the ASCII file to a GRID raster file by selecting **Conversion Tools » To Raster » ASCII to Raster** from **Arc Toolbox**. If possible, use the .txt file as the input or else use the ASCII file, **"X" River Typing » 05 Precipitation » PRISM_30** as the output, and **FLOAT** as the data type.

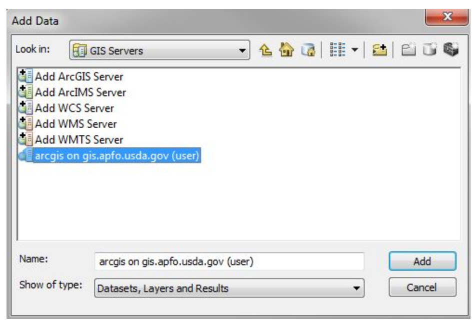
3.2.6 *Satellite/Aerial photography*

High resolution satellite/aerial photographs are required for virtual reconnaissance and channel planform identification. These can be obtained from a wide variety of free sources. For our purposes, 1-m resolution aerial photographs from the National Agriculture Imagery Program (NAIP) provide the best, most up-to-date source of imagery. Currently, NAIP images are obtained tri-annually for the lower U.S. during the spring and summer months. Images obtained during this period frequently represent river planform during average to low discharge due to drier conditions often experienced during these months. NAIP imagery can be downloaded through the USDA Geospatial Data Gateway or streamed directly to an ArcMap window via an image server. For small AOIs, NAIP (4-band) imagery can be downloaded directly from https://gdg.sc.egov.usda.gov/

<u>To add a NAIP image server connection</u>

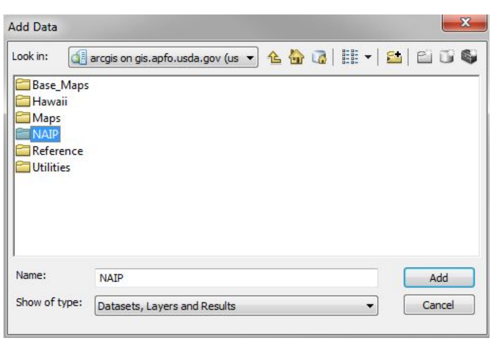
1) ▶ In ArcMap, click **Add Data » GIS Servers » Add ArcGIS Server** to open the ArcGIS Server Wizard.





2) ▶ Select **Use GIS Services** from in **ArcGIS Server Wizard** dialog box and click **next**. Input the USDA server URL (http://gis.apfo.usda.gov/arcgis/services) and click **Finish**.

3) ▶ A link to the USDA server should now appear in the **Add Data** window. Double click on the server and then the **NAIP** folder. Select the desired state(s) and click **Add.**



Note: An imagery basemap can also be added directly into ArcMap using the **Add Base Map** button from the drop down menu next to the Add Layer button.

4. Data Layer Preparation

4.1 Stream network and watershed generation

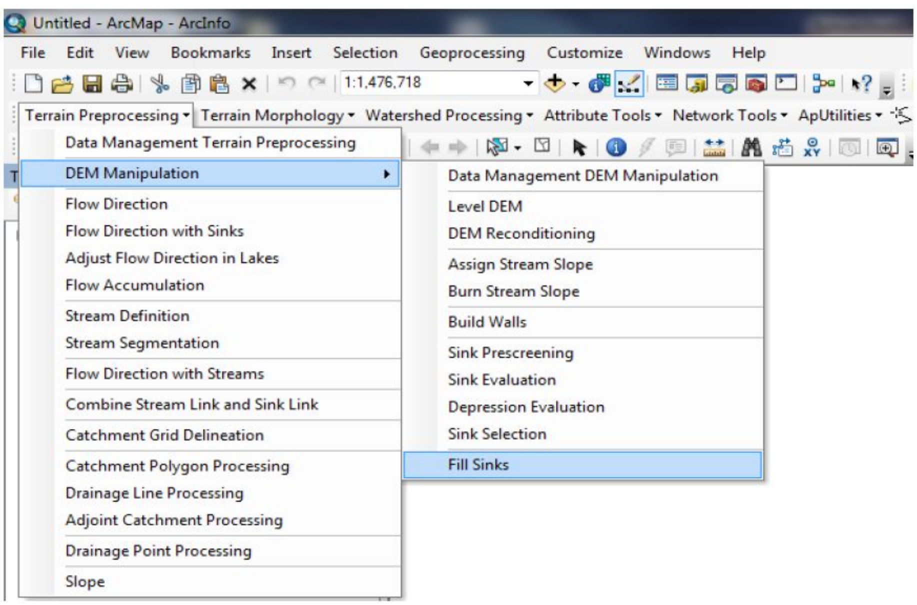
Note: If you are unfamiliar with Arc Hydro, you should review online software documentation and the following tutorial before executing the steps below.

http://waterinstitute.ufl.edu/events/downloads/ESRIArcHydroFloridaNov1507.pdf

1) ▶ Open a new instance of ArcMap and add **"X"_DEM_M** from **"X" River Typing » 03 Elevation » 01 Merge**.

2) ▶ Save the map as **"X"_ArcHydro** in the **"X" River Typing » 06 Modeling » 01 ArcHydro** folder. Arc Hydro will automatically create a **Layers** folder in this directory and export all data products to this location.

3) ▶ Select **Terrain Processing » DEM Manipulation » Fill Sinks** from the pull down menus on the **Arc Hydro** toolbar.



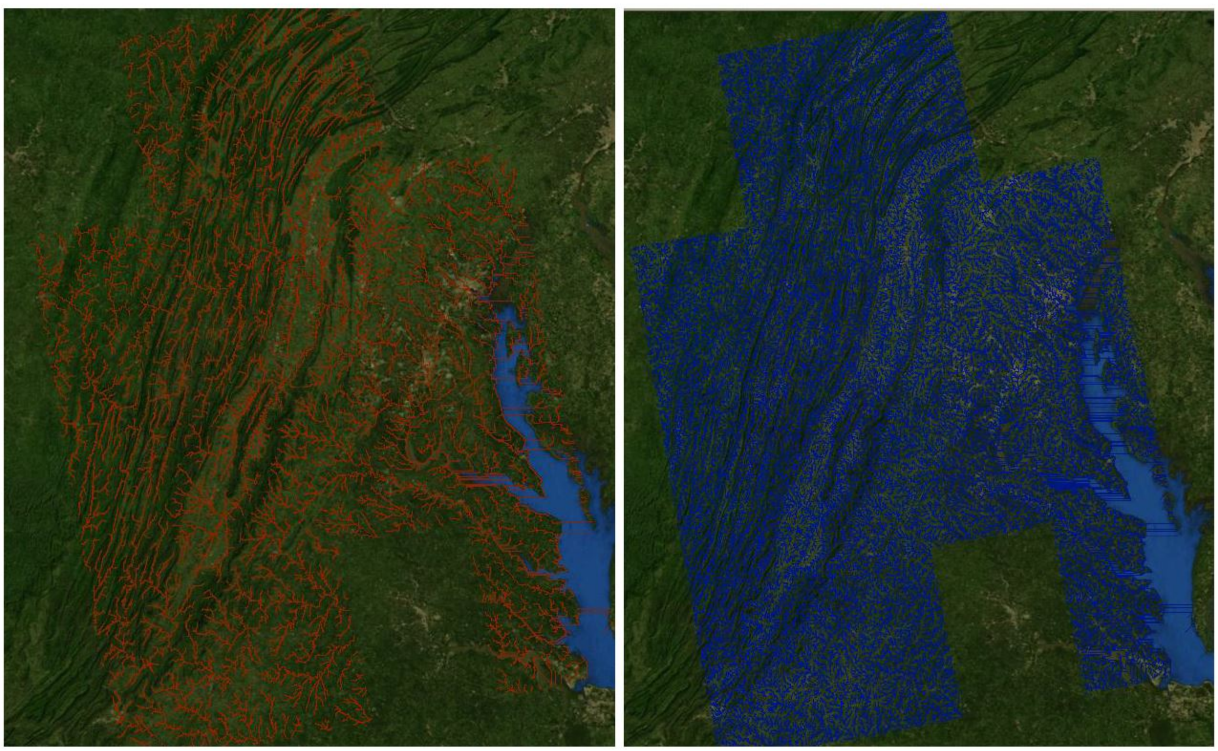
4) ▶ Set **DEM** to **"X"_DEM_M**, **Deranged Polygon** to **Null**, and **Hydro DEM** to **"X"_Fil**. Select the **Fill All** option and click **OK** to start.

5) ▶ Select **Terrain Processing » Flow Direction** from the pull down menu on the Arc Hydro tool bar. Set **Hydro DEM** to the **"X"_Fil** DEM created in the previous step, **Outer Wall Polygon** to **Null**, and **Flow Direction GRID** to **"X"_Fdr**. Click **OK** to start.

6) ▶ Select **Terrain Processing » Flow Accumulation** from the pull down menu on the Arc Hydro tool bar. Set **Flow Direction GRID** to the **"X"_Fdr** GRID created in the previous step. Set **Flow Accumulation GRID** to **"X"_Fac** and click **OK** to start.

7) ▶ Select **Terrain Processing » Stream Definition** from the pull down menu on the Arc Hydro tool bar. Set **Flow Accumulation Grid** to the **"X"_Fac** GRID created in the previous step. The **Number of cells** and **Area (square "unit")** fields of the **Stream Threshold** are automatically populated with the maximum number of cells in **"X"_Fac** and its total area. You may alter either of these values to set the FAC threshold. Finally Set **Stream Grid** to **"X"_Str_"FAC Threshold"** where **"X"** is the river name and **"FAC Threshold"** is an indicator of the threshold value used to generate the stream GRID (e.g. Kan_Str_50k [i.e., 50,000]). Click **OK.**

Note: Only pixels with FAC values greater than or equal to the specified threshold value are considered stream pixels. The threshold value determines stream network density and is entirely subjective; however, density should be guided by project goals. The stream generation process (**Steps 7-8**) should be run with varying threshold values until a suitable network is achieved. We have found that when using 10m DEMs, suitable thresholds generally fall between 50,000 and 100,000. Delete any files not related to the final network.



Left: Streamlines drawn with a 100,000 threshold (reasonable) Right: streamlines drawn with a 10,000 threshold (too many)

8) ▶ Convert the stream GRID to a network of vector lines by selecting **Conversion Tools » From Raster » Raster to Polyline** from ArcToolbox. Set **Input Raster** to the stream GRID created in Step 7. Set Field to **Value** and **Output** geometry type to **Polyline**. Select the **Simplify Polylines** option and change the **Output** directory to **"X" River Typing » 02 Stream Lines » 02 ArcHydro Stream Lines** folder. The file name should be the same as the GRID name used. Click **OK** to start.

Note: It is very important to record the threshold in file names. These values should also be recorded in the **Notes and Settings** file.

9) ▶ **Select Terrain Processing » Stream Segmentation** from the pull down menu on the Arc Hydro tool bar. Set **Flow Direction Grid** and **Stream GRID** to the files created in previous steps. Set **Sink Watershed Grid** and **Sink Link Grid** to **Null**. Set **Stream Link Grid** to **"X"_StrLnk**. Click **OK** to start.

10) ▶ Select **Terrain Processing » Catchment Grid Delineation** from the pull down menu on the Arc Hydro tool bar. Set **Flow Direction Grid** and **Link Grid** to the files generated in previous steps. Set **Catchment Grid** to **"X"_Cat_"FAC Threshold"**. Click **OK** to start.

11) ▶ Convert the catchment GRID to vector polygons by selecting **Conversion Tools » From Raster » Raster to Polygon** from ArcToolbox. Set **Input Raster** to the catchment GRID created in Step 10, select the **Simplify** polygons option, and change the **Output** directory to **"X" River Typing » 06 Modeling » 01 ArcHydro » ArcHydro Streamlines** folder.

12) ▶ Create a single-part polygon feature for the watershed by adding the **"X"_Watershed** layer from **"X" River Typing » 01Boundaries » 01 Watershed** folder to the map and use its boundary as a guide to select and then merge all sub-watersheds within it. Save a copy of the file to the same folder.

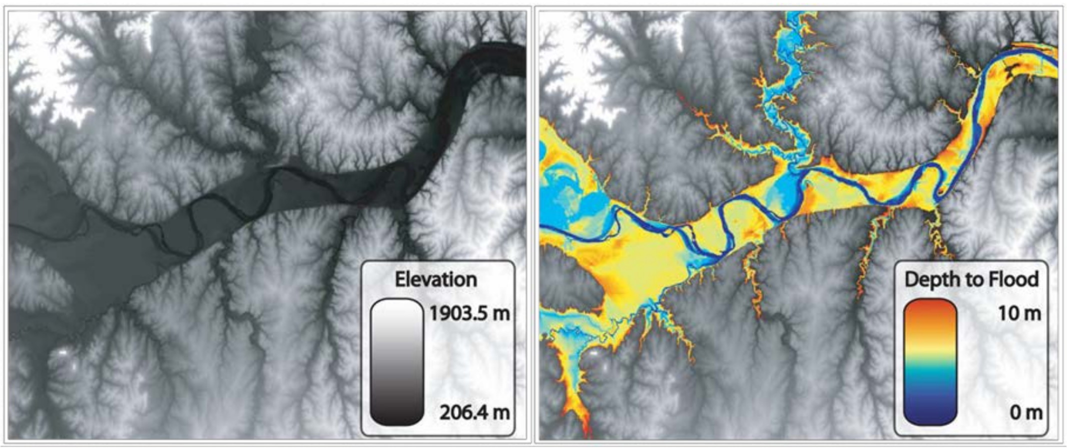
13) ▶ Using the newly generated watershed boundary to clip **"X"_DEM_M**. **Save** the resulting file as **"X"_DEM** and place it in the **"X" River Typing » 03 Elevation » 03 Analysis DEM**.

14) ▶ At this point, ArcHydro outputs that are used in the following FLDPLN process need to be exported as **.bil** files. Right click on **"X"_Fdr**, and select **Data » Export data.** Change the file type to **.bil** and save the file as **"X"_Fdr** to the folder **"X" River Typing » 06 Modeling » 02 FLDPLN » 01 FLDPLN Files**. Repeat this step with **"X"_Fil** and **"X"_Fac** files.

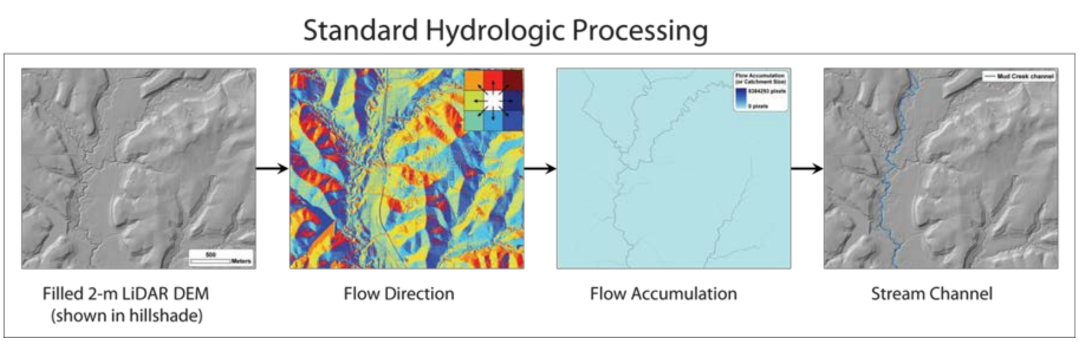
4.2 FLDPLN

4.2.1 Background

FLDPLN (Kastens 2008) was developed to estimate floodplain extent as a function of floodwater depth. This computational model is completely modular by design; it can be applied to any collection of stream segments and floodwater depths, with the resulting floodplain maps able to be merged seamlessly. The primary outputs from the model are "Depth to Flood" (DTF) values. Given a particular flood depth (equivalent to a river stage), inundated pixels in the floodplain are identified, and the minimum stage value at which the pixels are inundated (the DTF) is calculated.



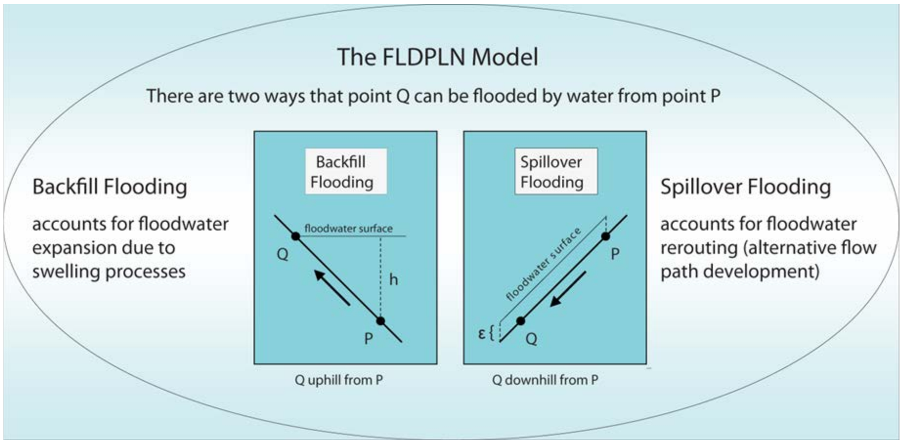
Underlying FLDPLN is an iterative, 2-dimensional, cellular flood model based on simple hydrologic flow principles, which are described below. A key advantage of FLDPLN is that it is largely deterministic and requires only a filled DEM and associated flow direction and stream network rasters, which are standard outputs from the ArcHydro Tools extension in ArcGIS®.



FLDPLN is based on the assumption that the floodwater path from any floodwater source point to any floodwater recipient point can be characterized using two fundamental mechanisms: backfill flooding and spillover flooding. Following backward trajectories from the flow direction map, backfill flooding approximates floodwater expansion. Nearly all of the floodplain areas identified by FLDPLN are specified using backfill flooding.

Spillover flooding establishes new floodwater routes in the floodplain by following forward trajectories. Spillover flooding occurs when backfill floodwaters breach a topographic flow divide and define a new floodwater flow path that (typically) finds its way back to the main downstream channel.

The strategy underlying the FLDPLN model is to backfill flood using small flood depth increments (to simulate floodwater expansion), applying spillover flooding between each step (to simulate new floodwater route development). Several examples using various DEM resolutions and river sizes were presented in Kastens (2008) which firmly established the use of FLDPLN for historic floodplain identification and mapping.



FLDPLN may be downloaded from the following location:
http://www.aquaticecolab.res.ku.edu/software/
www.macrorivers.org/resonate-model/

Instructions for installing and executing FLDPLN are included in the download and will not be duplicated in this manual. Please refer to FLDPLN documentation and tool help. Instructions for converting the DTF raster to a polygon are given below.

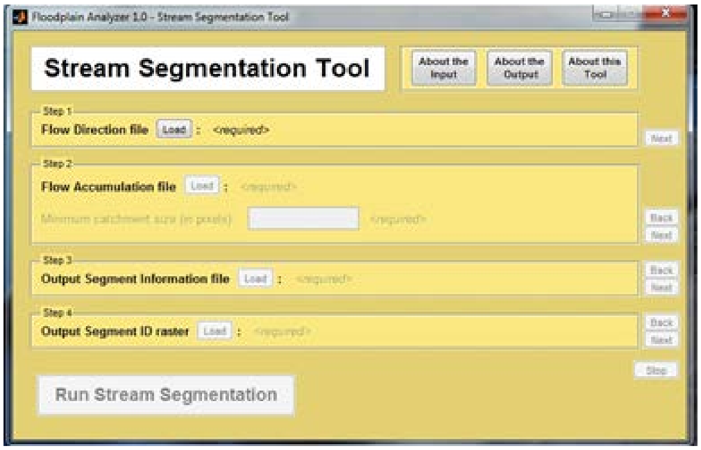
Note: The FLDPLN Model Tool is computationally intensive. It should be executed as soon as possible and allowed to run in the background or on a separate computer while other data preparation tasks are completed.

Note: FLDPLN and computer performance are greatly improved when FLDPLN's output directory and the Windows operating system are located separate physical drives. In addition to consuming most, if not all, of the systems processor and physical memory, FLDPLN generates very large temp files. If the operating system and FLDPLN's output directory are located on the same drive, frequent temp file read-writes will slow down Window's functions (including virtual memory). The hard drive will quickly become fragmented and the computer could potentially crash.

Note: If a separate hard drive is selected for FLDPLN's output directory, be sure to transfer all model generated data to the **"X" River Typing » 06 Modeling » 01 FLDPLN Files** folder when the model is complete and the DTF map has been finalized

4.2.2 Running the tools

FLDPLN was originally designed to run in MATLAB; however a stand-alone version of the model consisting of three program modules was developed so model functions could be executed by non-MATLAB users. To run the FLDPLN model in the context of RESonate, the stream network under study first must be partitioned into segments. The **Stream Segmentation Tool** is the first module of FLDPLN. It determines a natural segmentation pattern, whereby all headwater and confluence pixels are identified, and each headwater-to-confluence and confluence-to-confluence path defines a unique stream segment.



▶ **Step 1-2**: Load the Flow Direction and Flow Accumulation files created during preprocessing (**Note**: All raster inputs must be in .bil format).
▶ **Step 3**: Save the Output Segment Information file as **"X"_Seg** in **06 Modeling » 02 FLDPLN » 01 FLDPLN Files**.
▶ **Step 4**: Save the Output Segment ID raster as **"X"_ID.bil** in **06 Modeling » 02 FLDPLN » 01 FLDPLN Files**. Click the **Run Stream Segmentation** button.

▶ After the Stream Segmentation Tool has finished, load the resulting **"X"_ID** raster in ArcMap. Convert the file to a polyline using the **Conversion Tools » From Raster » Raster to Polyline** tool. Save the polyline shapefile as **"X"_ID** in the **01_FLDPLN Files** folder.

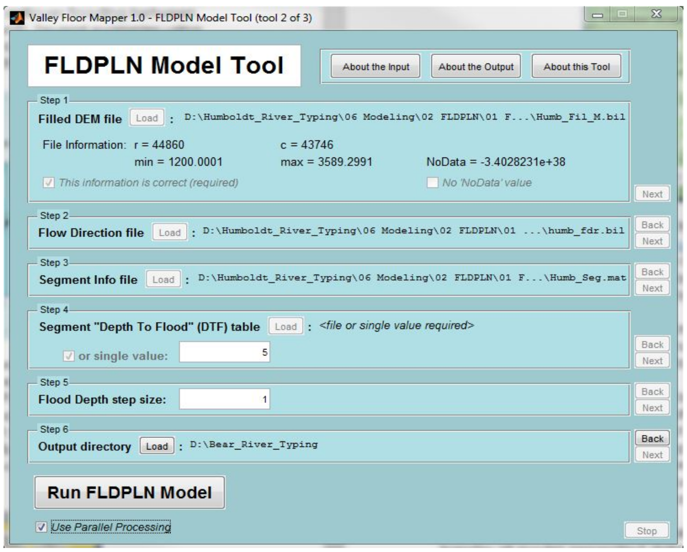
▶ In order to consolidate the smaller segments together, use the dissolve tool in **Data Management Tools » Generalization » Dissolve**. Dissolve the **"X"_ID.shp** file on **GRID_CODE** and save the file as **"X"_ID_Dis.shp** in **01_FLDPLN_Files** folder (leave all other fields as default)**.**

Compare the resulting polyline with the river streamline and DEM/Hillshade. Any extraneous or unwanted segments should be discarded before further processing. This may include segments that do not have a corresponding NHD line; where the channel is not well defined in the DEM (i.e., extremely flat areas). Segments in flat areas severely slow processing in subsequent steps. Some predetermination of site interest, including selecting out urban areas, canals, and reservoirs can speed processing and lead to better floodplain outputs.

▶ After the **"X"_ID_Dis.shp** polyline has been edited, export the attribute table as a text file. Open the text file as an Excel spreadsheet. Delete the **OID** column, and rename the **GRIDCODE** column "**Segment ID**". Create an adjacent column named "**DTF Value**" and populate the Segment ID's with the desired depth to flood (DTF) values. **Save** the Excel file as **"X"_DTF.xlsx** in **01 FLDPLN Files** folder.

Note: Determining the Depth to Flood (DTF) is a subjective task and involves some trial and error. Depending on the complexity of the river network and landscape morphology, a single DTF value may be adequate for all segments. If segment specific values are needed, segments can be investigated using pixel inspector with NAIP imagery and DEM hillshade.

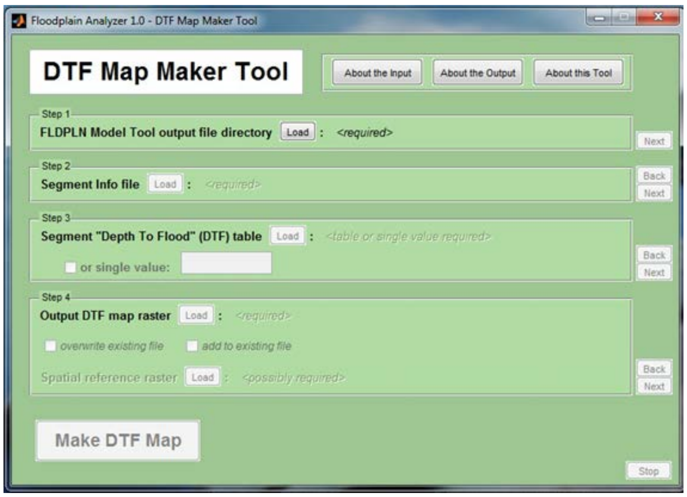
The **FLDPLN Model Tool** is used to independently apply the model to each segment, with the maximum step size for flood depth and flood iteration being specified by the user.



▶ **Step 1:** Load the filled DEM, or load a new DEM with large water features clipped from the DEM extent (**Note:** For the FLDPLN Model Tool <u>only</u>, the Filled DEM file can have waterbodies extracted for faster processing).
▶ **Step 2:** Load the Flow Direction file (**NOTE:** this must be the same FDR file used in the Segmentation Tool).
▶ **Step 3:** Select the Segment Info file created using the Segmentation Tool.
▶ **Step 4:** Load the DTF table or enter a single value for all segments.
▶ **Step 5:** Enter a Flood Depth step size. Use "**1**" for the most complete coverage.
▶ **Step 6:** Choose an output directory location where all resulting segments will be stored (if using Parallel Processing, a **segment_files** folder will be created in this location to store completed and temporary segments).
▶ Select the **Use Parallel Processing** radio button if you meet all system and processing requirements. This will speed processing by partitioning segment processing among disks. Click the **Run FLDPLN Model** button.

Resulting DTF maps are integrated seamlessly into a single DTF raster by the **DTF Map Maker Tool** module. The DTF raster can then be contrasted against DEMs to identify areas of under-flooding (where “valley full” flooding has not been achieved) and over-flooding (where critical valley flow divides have been crested and the valley is improperly overflowing). Identifying either type of occurrence relies on user judgment to some degree. In either case, the modular nature of the model makes it is possible to increase or decrease flood depths in individual segments. Once the DTF map for a watershed has been finalized, its extent is converted to a polygon. This polygon is used in RESonate to determine valley floor width and ultimately valley width and the left and right valley side slopes.

Note: If necessary, before running the DTF Map Maker Tool, you may delete extraneous streamline IDs from DTF table so that they are not mapped in the final DTF map.



▶ **Step 1:** Locate the directory where segment files from the FLDPLN tool were stored.
▶ **Step 2:** Select the **Segment Info** file created using the Segmentation Tool.
▶ **Step 3:** Load the **DTF table** or enter a single value for all segments.
▶ **Step 4:** Save the **Output DTF map raster** as **“X”_DTF** in the **"X" River Typing » 06 Modeling » 02 Valley Floor Extent** folder. Use **“X”_Fil** as the **Spatial reference raster**. Click the **Make DTF Map** button.

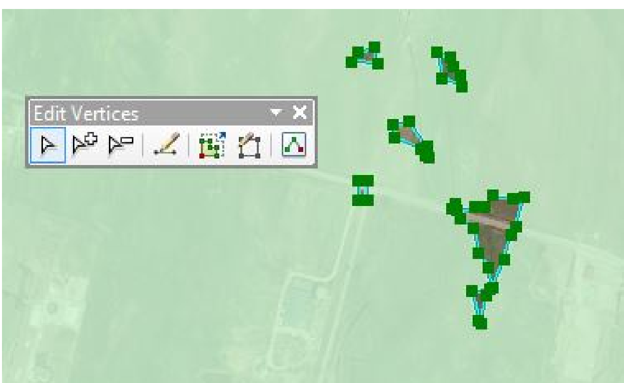
4.2.3 Valley floor polygon

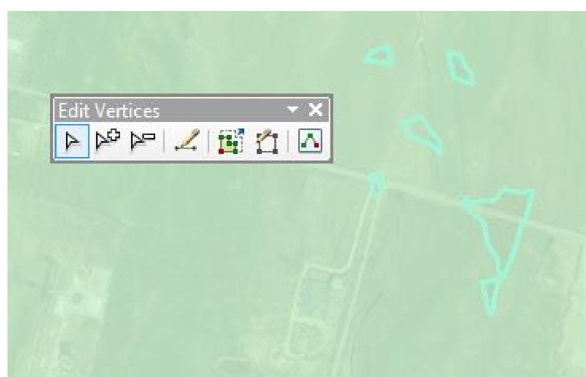
1) ▶ The finalized DTF raster must be reclassified into flooded and non-flooded pixels before it's converted to a polygon. Select **Spatial Analyst Tools » Reclass » Reclassify** from Arc Toolbox. Input the DTF raster and set the **Reclass** field to **Value**. Reclassify non-zero values within the DTF range as **1** and all values ≤ 0 and/or no-data values to **NoData**. Save the file as **"X"_DTF_re** in the **"X" River Typing » 06 Modeling » 02 Valley Floor Extent** folder.

2) ▶ Convert the **"X"_DTF_re** raster to a polygon. Save the resulting polygon as **"X"_Valley_Floor** in the **"X" River Typing » 06 Modeling » 02 Valley Floor Extent** folder.

3) ▶ The valley floor polygon may contain small holes due to artifacts in the DEM, such as isolated hills within the valley floor. Create a uniform valley floor polygon by using the **Dissolve** tool described in **Section 3.2.4, Step 6**. Using the **Eliminate Polygon Part** tool will also close remaining holes. If neither of these procedures work, perform a "Union and Dissolve" process outlined **HERE**.

4) ▶ The tools described above may not fill all holes in the polygon. Examine the valley floor polygon with satellite imagery to find holes that do not correspond to a true obstruction to flood waters. Close the holes by editing the polygon and selecting **Edit Vertices,** then **right click** on any node in the hole and select **Delete Vertex**. **Save** the polygon file often as you edit. **Note:** Valley floor width and other measurements will be taken by transects crossing the valley floor layer. If holes in the layer will not obstruct accurate measurements from being collected, they can remain in the layer.

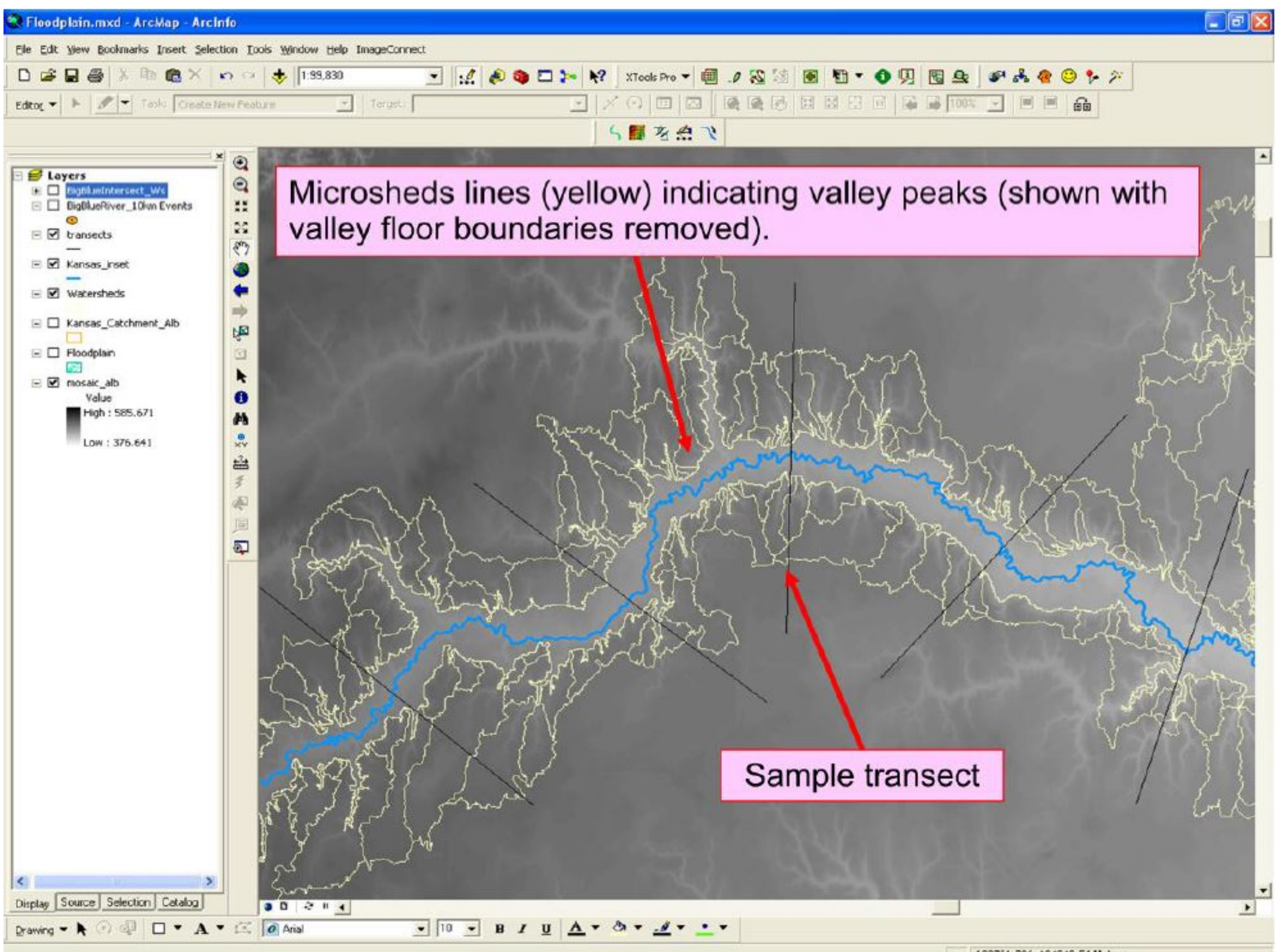


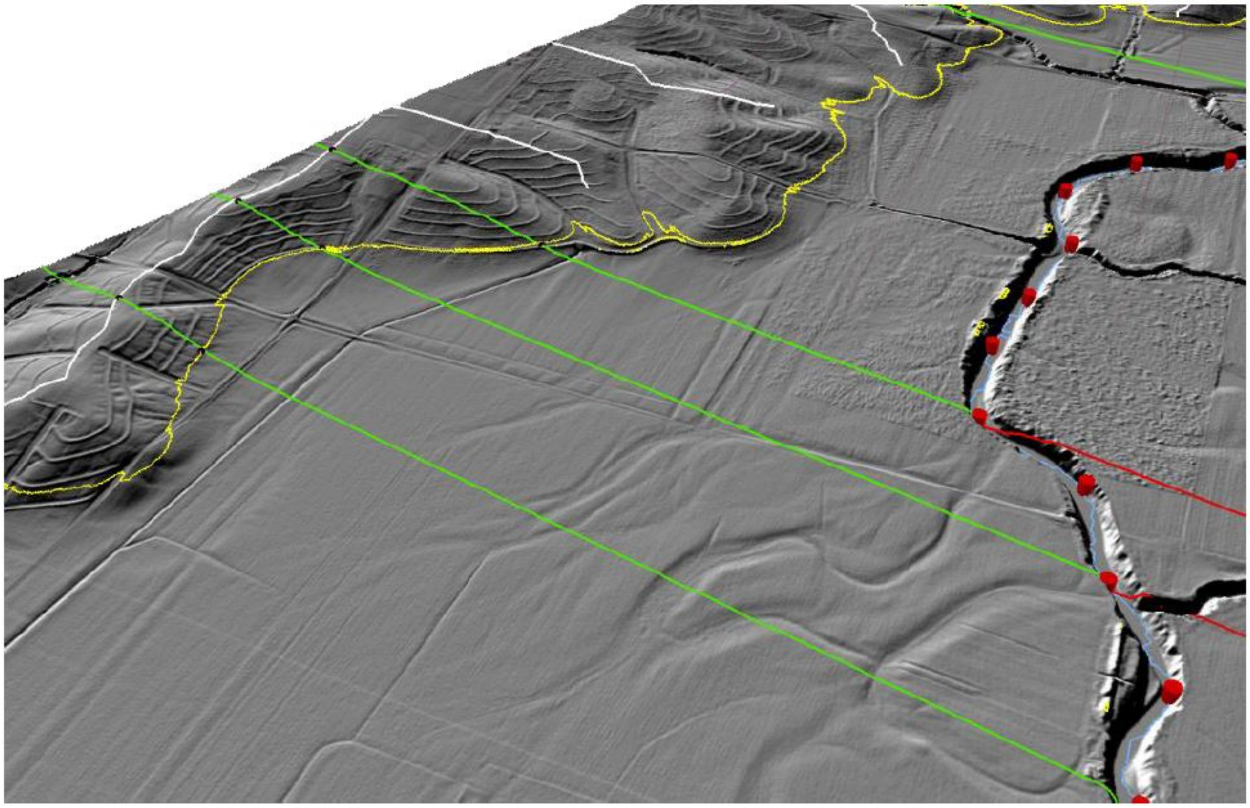


4.3 Additional data preparation

4.3.1 Microshed generation

Identifying the boundaries of the river valley and its width is difficult, especially in highly dendritic networks with low topographic relief. Our solution to valley identification is to use the valley floor polygon generated with FLDPLN as a guide to identify hydrologic unit (watershed or sub-watershed) boundaries coinciding with the valley top. This is achieved by generating a large number of very small watersheds (e.g. < 1-2 km2), termed microsheds, within each study watershed. To reduce the amount of extraneous data, all microsheds that do not intersect the boundary of the valley floor polygon are deleted; this eliminates microsheds that are completely interior or exterior to the valley floor polygon. The remaining microshed polygons are converted to polylines, and line segments overlapped by the valley floor polygon are deleted. The line segments that remain are used to identify the valley top. When used together, the valley floor polygon boundary and remaining microshed boundaries essentially envelop the valley walls on both sides of the channel. For any particular valley location (cross section), elevation values at these lines and horizontal separation between these lines enable automatic estimation of, valley width (VW), the ratio of VW and VFW (RAT), and left and right valley side slopes (LVS and RVS).





1) ► Open a new instance of ArcMap and add **"X"_Fdr** and **"X"_Fac** to the map. Save the map document as **"X"_River_Microsheds** in the **"X" River Typing » 07 Microsheds** folder.

2) ► Repeat **Steps 7 – 12 of Section 4.1** and save the outputs to the **"X" River Typing » 07 Microsheds** folder. Generate high density stream networks by selecting low flow accumulation thresholds. Users should generate a number of networks of varying density to see how flow accumulation threshold values affect the size of the microsheds. The goal is to generate microsheds whose boundaries represent the ridgelines of the river valley. **Note:** When using 10m DEMs, thresholds between 5,000 and 10,000 work well.

Note: A large number of artifact watersheds will be generated in the extremely flat valley flow. It is best to judge whether or not microshed boundaries represent valley ridges with the opaque valley floor polygon overlaid on the microshed layer and the DEM.

3) ►Once a microshed solution has been chosen, select **Data Management » Features » Polygon to Line** from Arc Toolbox to convert **"X"_Cat_"FAC Threshold"** into polylines. Save the file as **"X"_MicroPoly.shp**.

4) ►Remove extraneous microshed polygons by **editing** the **"X"_MicroPoly** file and using the **Select Layer by Location** tool to select any microshed line segment that does not intersect with the boundary of the valley floor polygon. Use **"X"_MicroPoly**

as the Input Feature Layer, **INTERSECT** as the Relationship, **“X”_DTF.shp** as the Selecting Features, and the Selection type as **NEW_SELECTION**. **Select** the Invert Spatial Relationship button. Press **OK**. Delete the selected segments, and save the edits.

5) ►Select **Analysis » Overlay » Erase** from Arc Toolbox. Use the valley floor polygon to erase all microshed polygons in the valley floor. Save the output as **“X”_MicroErase**.

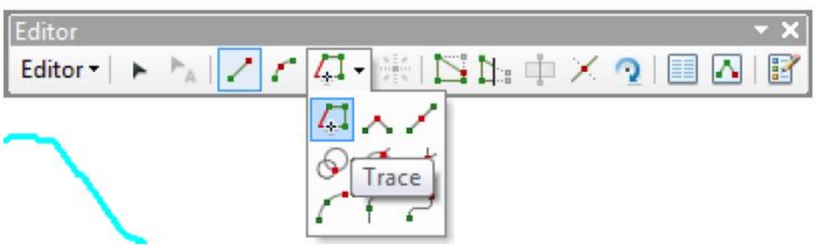
Note: The resulting files will ensure that sample transects will first intersect the boundary of valley floor before intersecting a microshed line (valley ridge). See 3D figure above.

4.3.2 Stream network tracing and attributing

RESonate requires a vector network composed of single-part polylines (each line representing a river from origin to mouth). Vector stream networks generated by ArcHydro consist of multipart polylines segments that have no relevant stream name attributes. The Arc Hydro stream network must be retraced and properly attributed before it can be used in an FPZ analysis.

1) ► Create a new shapefile in **“X” River Typing » 02 Stream Lines » 02 ArcHydro Stream Lines** named **“X” Streamlines**. Set the file type to Polyline. Add this shapefile and the **"X"_Str_"FAC Threshold"** polyline file created during ArcHydro Modeling.

2) ► Start an editing session on **“X”_Streamlines**. Select **Construct Features** and **Line** from the Editor tab to enable feature editing. Select the **Trace** tool from the Editor Toolbar.



3) ► Open the **Snapping toolbar** to ensure that snapping in use and that Edge, Vertex, and End snapping are enabled.

4) ► Start from the longest flow path in **"X"_Str_"FAC Threshold"** and trace it as a single feature, starting at the most upstream point and ending at its confluence. Repeat this procedure for all streamlines.

Note: Save edits frequently to avoid data loss.

Note: It's easier to start from the longest flow paths and finish with the shortest.

Note: NHD Streamlines with labeled stream names can be a useful reference.

5) ►When finished, save your edits and stop editing. Open the **"X"_Streamlines** attribute table, add a field named **StreamName** as a Text field with a maximum length of 40 characters. Next, add a field named **Length** and set it as Double.

6) ► Right click on the **Length** field and select **Calculate Geometry**. Calculate the length in **kilometers**.

Note: If you know the sampling distance you intend to use for data extraction in RESonate, you may delete any streamlines that are shorter than this distance.

7) ► Restart the editing session and populate the **StreamName** field with stream names from the NHD Streamlines. This may be done by manually entering the names or by using the Attribute Transfer tool in the Spatial Adjustment toolbar.

Note: Stream names cannot have spaces and should not contain special characters (e.g. Potomac River N. Branch should be PotomacRiverNBranch).

8) ►A topology check must be run to ensure that all stream segments are properly connected and no errors persist that could interfere with later processes. Use ArcCatalog to create a new geodatabase named **Topology** in the **"X" River Typing » 02 Stream Lines » 02 ArcHydro Streamlines** folder.

9) ► Right click on **Topology**, select **New » Feature Dataset** and name it **Topology**. Right click on the feature dataset and select Import then **Feature Class (Single)**. Navigate to **"X"_Streamlines** and save the file as **"X"_Topology**.

10) ► Right click on the feature dataset, select **New** then **Topology**. Select **"X"_Topology** as the only layer to analyze. In the New Topology window, add the following rules:

Must Not Have Dangles
Must Not Have Pseudo Nodes
Must Be Single Part
Must Not Self-Overlap
Must Not Self-Intersect

Click **Next** then **Finish**. When asked to validate topology, choose – **Yes**.

11) ► Add **"X" Topology** to ArcMap. The highlighted lines contain at least one of the specified errors. Start an edition session on **"X"_Topology** and open the Topology toolbar. Once an error has been corrected, click Validate Topology in Current Extent. Use the **Validate Entire Topology** option to ensure that all topological errors have been truly corrected.

Note: Save edits frequently.

Note: The upstream most vertex of each stream will be marked as a Dangle error. These do not need to be corrected.

Note: Ensure that all lines start at the upstream and end at the downstream end. You can check this by changing the line symbol to arrows. If a line's direction is reversed, start editing and double click on the line to expose its vertices. Right click on the line and select Flip from the menu.

12) ► Export the topology as a shape file and save it as **"X"_Streamlines_C** (C stands for corrected) in the **"X" River Typing » 02 Stream Lines » 03 Final Stream Lines** folder and add this file to ArcMap.

4.3.3 Streamline route creation

Note: RESonate tools require polylines that have been converted to route features. At this stage, streamline segments must have their route features processed individually. This can be cumbersome, due to using batch processing, and will be rectified in future versions of RESonate.

13) ► Change the line symbology of **"X"_Streamlines_C** to ensure that all streams are "flowing" in the same direction (headwaters to confluence). This can be done by changing the line symbology and adding a **green** arrow as the **start** point, and a **red** arrow as the **end** point.

Note: The ultimate goal is to "flip" the streamlines so that their headwaters are labeled as the end point, and the confluence is labeled as the start point. Color coding the start/end points can help visualize this change.

14) ► When all stream directions look correct, run **Split Streamlines Save Polylines** tool. Input **"X"_Streamlines_C**, select **StreamName** as the sorting field, and create and save the output to **"X"_Segments** folder. Press **OK**. Load segments to ArcMap.

15) ► Convert the segments to routes by opening **Linear Referencing Tools » Create Routes**, right click and choose **Batch…** processing from Arc Toolbox. Set the segments (i.e., **"SegmentName"**) as the Input Line Features, **StreamName**, as the Route Identifier Field, **"SegmentName"_R** as the Output Feature Class, and set the output directory to the **"X" River Typing » 02 Stream Lines » 03 Final Stream Lines » 01 Points** folder. Ensure that Measure Source is set to Length, all other options can be left as default. Click **OK** to start.

16) ► Calibrating routes assigns measure values to the route lines. The measure values are generated by using an outside source such as ground sampling points separated by a known distance. Route events such as RESonate sample points and transects cannot be generated if the route has not been calibrated to a point file. Generate route calibration points by selecting **Data Management Tools » Features » Feature Vertices to Points**, right clicking and choose **Batch…** processing from Arc Toolbox. Set Input Features to **"SegmentName"_R**, the Output Feature Class to **"SegmentName"_P**, and save the file in **"X" River Typing » 02 Stream Lines » 03 Final Stream Lines » 02 Points** folder. Set Point Type to **Start** and then click **OK**.

17) ► Select **Linear Referencing Tools » Calibrate Routes**, right click and choose **Batch…** processing from Arc Toolbox. Set Input Route Features to **"SegmentName"_R**, the Route Identifier Field to **StreamName**, Input Point Features to **"SegmentName"_P**, Point Identifier Field as **StreamName**, and Measure Field to **Orig_FID**. Set the Output Route Feature Class to **"SegmentName"_F** and save it in the **"X" River Typing » 02 Stream Lines » 03 Final Stream Lines » 03 Final** folder. Use the default option for all other fields.

18) ► Merge segments in the **03 Final** folder into a single polyline **"X"_Final_Streamlines**. Add a **"LengthKM"** field to the **"X"_Streamlines_Final** polyline, and calculate the length in Kilometers.

4.3.4 Channel belt generation

The channel belt (or meander belt) is a band that runs along the valley floor along the valley floor that completely contains a meandering channel. Not all streams have a channel belt, and those that do may or may not exhibit a continuous channel belt. A meandering stream in a broad valley floor may have a wide and sinuous channel belt that ends abruptly when the stream enters a constricted valley or a reservoir.

Channel belts are commonly generated by placing points on meander bends nearest to the valley walls. The belt is typically delineated by drawing lines connecting these points along the left and right sides of a stream. Ideally, all meanders of the stream channel should be contained entirely within this channel belt envelope, and the envelope should be contained entirely within the river valley.

1) ► Make a copy of **"X"_Streamlines_Final** in the **"X" River Typing » 08 Channel Belt » 01 Generalized Streams** folder and rename it **"X"_Generalized**.

2) ► Create a new polyline shapefile named **"X"_Channel_Belt** in the same folder. Add a field named **SIDE** and set it as a Text field with a maximum of 5 characters. Create another field named **StreamName** and set it as a Text field with a maximum of 50 characters.

3) ► Add **"X"_DEM**, **"X"_Channel_Belt**, and the copy of **"X"_Generalized** to ArcMap and start editing **"X"_Generalized**.

4) ► Select individual or small groups of streams with the Edit tool in the Editor Toolbar, then click on the Generalize tool in the Advanced Editing toolbar.

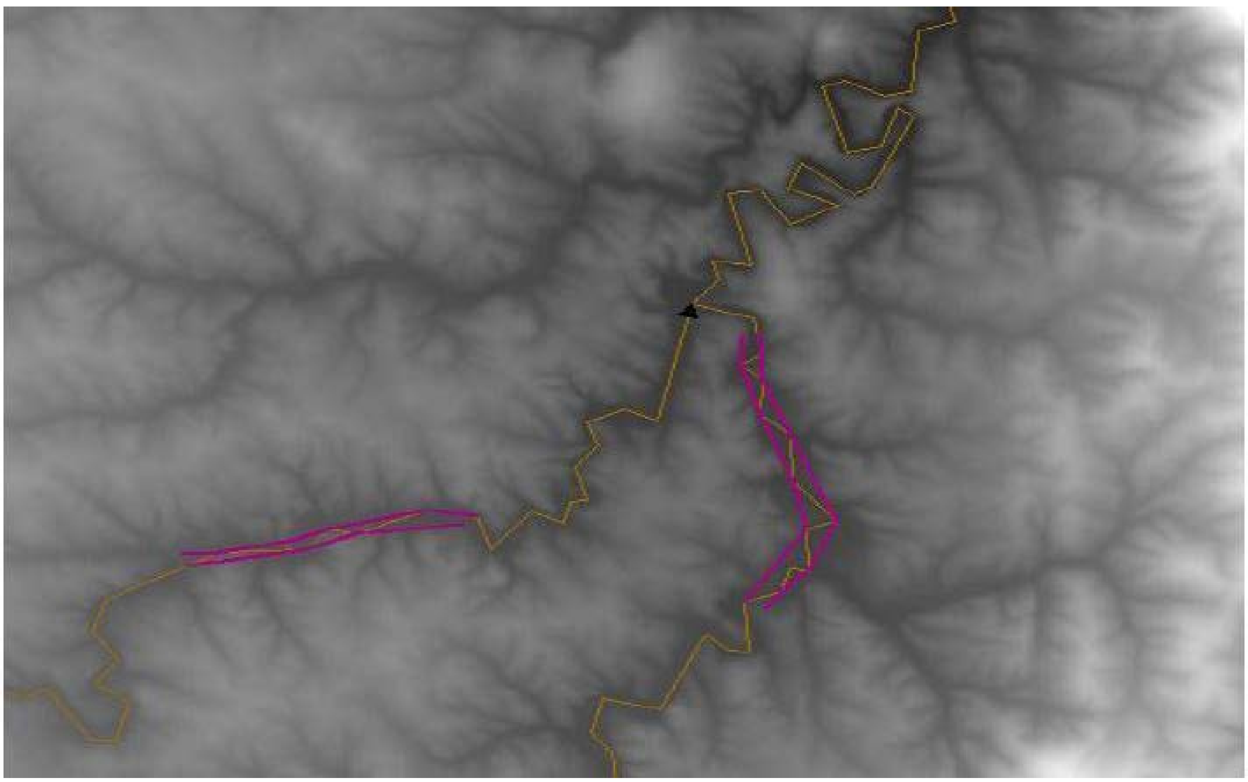
5) ► Set the Maximum allowable offset and click OK. Several values should be tested before settling on a solution. The goal is to generalize stream lines to a point where minor bends are removed and the apices of major meander bends and the general meander pattern of the river are clearly visible. Once the stream lines have been sufficiently generalized, save the edits and stop editing.

Note: A constant map scale should be used throughout channel belt generation to ensure that judgments about which stream line extrema constitute the highest local meander amplitude are consistent.

6) ► Make sure **"X"_DEM** and **"X"_Generalized** are visible in the ArcMap window and that Vertex snapping is the only snapping enabled. Start editing the **"X"_Channel_Belt** layer. Generate a line that connects meander vertices on one side of an **"X"_Generalized** stream line. Attribute the newly created channel belt line with the appropriate stream name and side (right and left sides are based on the perspective of an observer looking downstream). Repeat the process until both sides of the channel belt have been generated for each stream line.

Note: The DEM should guide channel belt line generation. Channel belt lines should connect adjacent meander vertices; however, bends in the valley may result in channel belt lines that protrude outside of the valley floor and cut through the valley side slope. This is especially a problem when a meandering stream runs up against one side of the valley wall as it goes through a valley bend. This can be avoided by generating a channel belt line that curves around the valley bend instead of directly connecting vertices in the generalized stream layer.

Note: Do not generate a channel belt where the stream doesn't meander within its valley (reservoirs, constricted valleys, or straight streams in sinuous valleys).



Channel belt lines generated from generalized stream lines provide good estimate of channel belt width and sinuosity. Unfortunately, the generalization procedure can lead to situations where the stream line protrudes several meters outside of the channel belt lines. If a sample point is generated in one of these problem areas, its corresponding sample transect will fail to intersect one side of the channel belt and the RESonate tools will return a null or inaccurate width and sinuosity value. The easiest solution is to apply an offset to the channel belt lines. RESonate's channel belt tools have been designed to automatically subtract the offset value from channel belt width. Channel belt sinuosity is unaffected by the offset. Using a series of tools to automate the offset process is cumbersome and time consuming. It is faster to apply the offset by manually editing a copy of the channel belt file.

1) ► Make a copy of **"X"_Channel Belt** in its current directory and rename it **"X"_CB_Offset**. Add the file to ArcMap.

2) ► Start editing **"X"_CB_Offset**. Label or apply a different symbology to each side. Select a channel belt line and select the Copy Parallel tool from the Editor Toolbar. Set the offset distance (a large offset distance is not needed), set Side to whichever value will result in a line outside the selected line, and check the Treat each selection as a single line option.

3) ►Once an offset line has been generated, select the original channel belt line and delete it. Repeat this process for each channel belt line (groups of lines can be selected offset at once).

4) ►The offset will cause overlaps at the confluences. Remove these with the **Trim** tool in the **Editor Toolbar**. Save edits when finished and be sure to save the offset value in the **Notes and Settings** file.

5. Automated Hydrogeomorphic Data Extraction

5.1 Background

The REsonate Toolbox was built to automate the extraction of hydrogeomorphic variables for use in the delineation of Functional Process Zones. The toolbox consists of 5 mandatory script tools and one optional script tool. The script tools are described in detail below. The results for all of the tools are reported in the Master Table which is stored in the file geodatabase created by the first script tool. It is important to run the scripts in order since some scripts work off of results from earlier scripts.

Note: In order to run the toolbox the user <u>must</u> save the .mxd first. The .mxd is automatically re-saved as each script tool completes

Installing REsonate Toolbox:

▶ Requirements: ArcGIS 10 or above, Spatial Analyst, 3D Analyst

▶ It is important to keep the toolbox and all of the script folders in the same structure as they originally existed. See the **Appendix** for detailed figures illustrating the hierarchical script relationship.

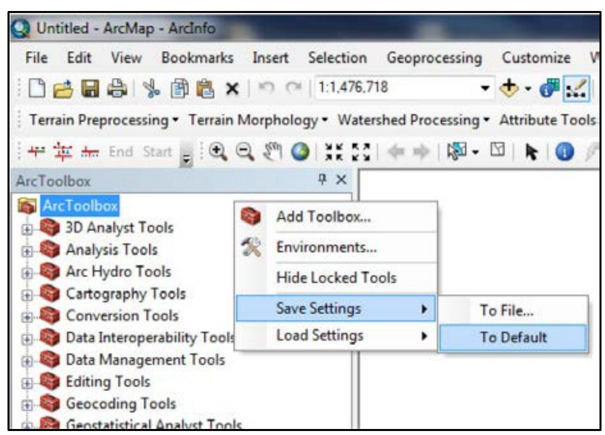
1) ▶ Open ArcMap and open the **Arc Toolbox** tab.

2) ▶ Right Click in the **Arc Toolbox** tab and select **Add Toolbox** from the menu. Navigate to where the RESonate Toolbox was saved, select the **RESonate Toolbox**, and click **Open**.

Tools Included:

1 – RESonate Analysis Tool – Start
2 – Generate Transects
3 – Calculate Widths
4 – Side Slope
5 – Calculate River Sinuosity
6 – Calculate Channel Belt Sinuosity

3) ▶ Right Click in the **Arc Toolbox** tab, select **Save Settings » To Default** (this will keep the RESonate Toolbox in ArcToolbox no matter what ArcMap project you open or start).



5.2 RESonate Tools

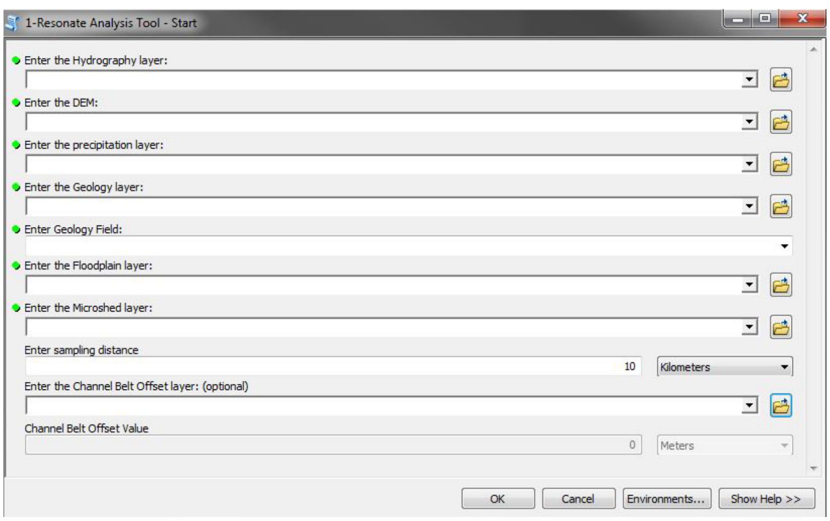
5.2.1 Project Initiation

1) ▶ Add the finalized streamlines, DEM, PRISM, generalized geology, valley floor polygon (FLDPLN layer), microsheds, and channel belt lines (if applicable) to ArcMap. And save the map in the **"X" River Typing » 13 Resonate** folder.

2) ▶ Click the **1-RESonate Analysis Tool** in the **RESonate Toolbox** to initiate the data extraction process.

This first script tool receives the input data layers needed to run the RESonate tools. The inputs will be recorded in a text file called **MXDNAME_RESdatalayers.txt** that will be automatically saved in the same location as the .mxd. The script tool will also create a file geodatabase that will house the results from the RESonate Analysis. The geodatabase will be named after the hydrology layer inputted into the tool and it will be stored in the same location as the .mxd. A **Master Table** called **"HydrologyLayerName"_MasterTable** will also be created and stored within the geodatabase. This table will contain all data extracted by the RESonate tools.

3) ▶ Input the appropriate data layers and select the desired sampling distance and units and click **OK**. Sampling points will be generated at the inputted sample distance and stored in the geodatabase. Precipitation (Mean Annual Precip), Geology (Geology), Elevation (Elevation) and Down Valley Slope (DV Slope) will be calculated at each sample point. The names of the updated fields are in parenthesis.



Note: The **Channel Belt Offset Value** is only enabled if a channel belt offset layer is provided.

Note: Additional help about each input variable is available in the tool help.

Note: It is important that all of the input variables are in the same *projected* coordinate system.

Note: Procedures for creating and formatting the required data layers are outlined in the preceding sections of this manual; however, basic layer requirements are summarized below.

Required Variables:

Hydrology – Must be a line route, attributed with stream name (StreamName and LengthKM) and have only one segment for each stream name.

DEM – Requires an elevation raster dataset. The units of the output will be the same as the DEM.

Precipitation – Mean Annual Precipitation raster dataset.

Geology – Polygon geology data layer.

Geology Field – The field in the Geology polygon layer that holds the attributes for geology type (this must be a text field).

Floodplain – This is a specialty layer that must be created by the user prior to running the tool. See the FLDPLN modeling section and FLDPLN documentation for more details.

Microshed – This is a specialty layer that must be created by the user prior to running the tool. See Microshed Generation section for further details.

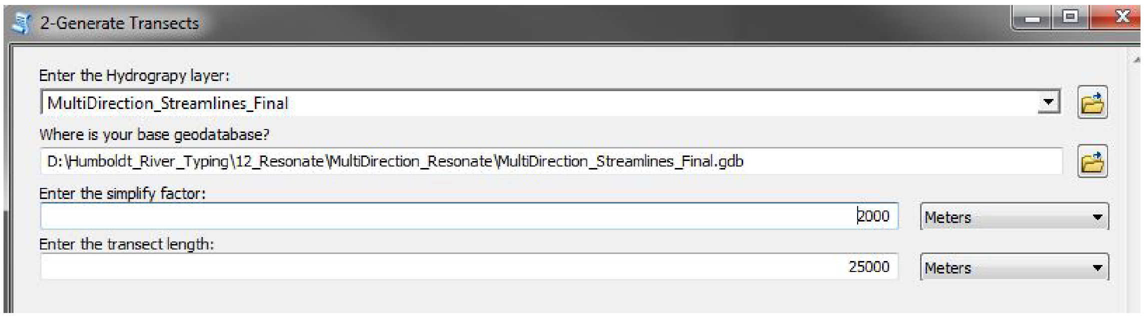
Sampling Distance – The distance between samples. The input must be in kilometers, meters or feet only.

Channel Belt Offset (Optional) – This is a specialty layer that must be created by the user prior to running the tool. See the Channel Belt section for more details. It is recommended to use an offset of the actual channel belt because there can be places where the river channel overlaps the channel belt. The offset value is automatically subtracted from the channel belt width calculations.

Channel Belt Offset Value – The offset value used for the channel belt. If no offset was used set the Channel Belt Offset Value to 0. This will result in null values for Channel Belt width in some areas. This parameter won't be active unless a Channel Belt Offset layer is entered.

5.2.2 Transect generation

1) ►Click 2-Generate Transects in the RESonate Toolbox. This tool will sample transects perpendicular to the valley along the hydrography layer at each site location. The resulting data layer called **transect_simple** will be saved within the Smoothing dataset within the file geodatabase created in the earlier step (stored in **"X" River Typing » 09 GDB**).



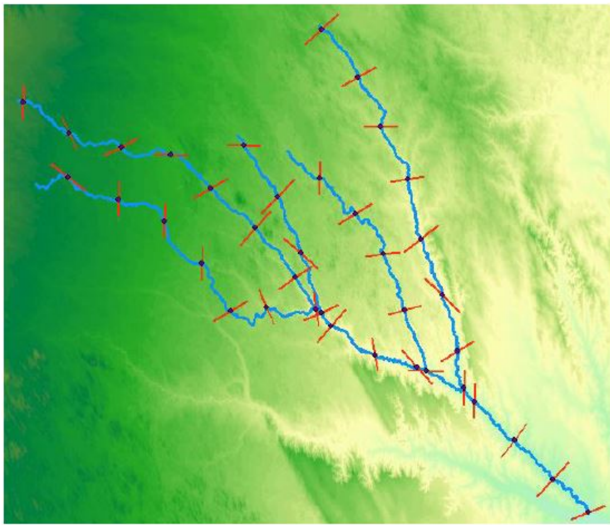
2) ►The first two input variables will be automatically populated based on the inputs entered in the first script tool. Input the simplify factor and desired transect length and click OK to run. The resulting **transect_simple** data layer will be automatically added to the ArcMap session.

Note: The script requires a simplify factor because high resolution hydrography can have minute turns and direction changes that can result in transects generated at odd angles. The simplify factor will be different depending on the river and its valley. The user will have to test several simplify values before the appropriate one is determined.

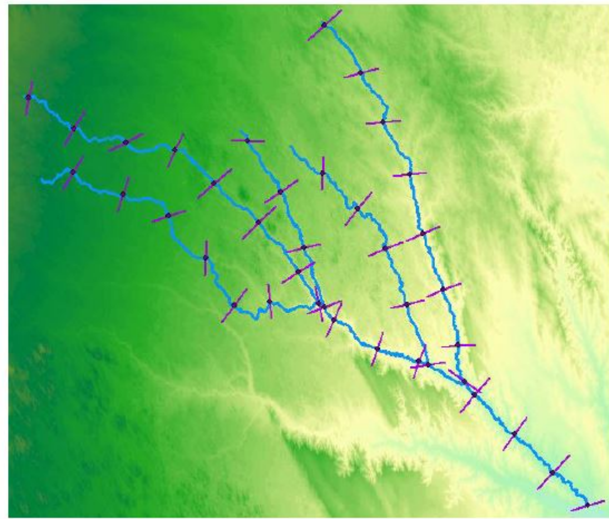
Here are some general guidelines:

1) The smaller the number the less simplified the stream will be and the more skewed transects will be (see figure below).
2) If too large of a number is selected the script will error out with a warning about the simplify factor. **Note:** ~2000 is a good number to start with, while ~3000 is the point that error warnings are generated.
3) Even if a suitable simplify factor is found **manual correction of transect orientation will most likely be needed**. Overlay the **transect_simple** data layer on the DEM to ensure that each transect is perpendicular to the river valley. Correct any aberrant transects by editing the **transect_simple** data layer.

Note: The user should set the transect length value so that the widest section of the river valley is crossed. If the selected transect length is too short, width measurements will not be able to be calculated in areas where transects do not completely cross the river valley.



Transects without simplify factor



Transects with simplify factor

5.2.3 *Valley, valley floor, and channel belt widths*

1) ► Click **3-Calculate Widths** in the **RESonate Toolbox**. This script tool will calculate the widths for the valley, valley floor, and the channel belt (when applicable). The following fields will be populated in the **Master_Table**: Valley Width, Valley Floor Width, Ratio VW to VFW (Ratio of Valley Width to Valley Floor Width) and Channel Belt Width (when applicable).

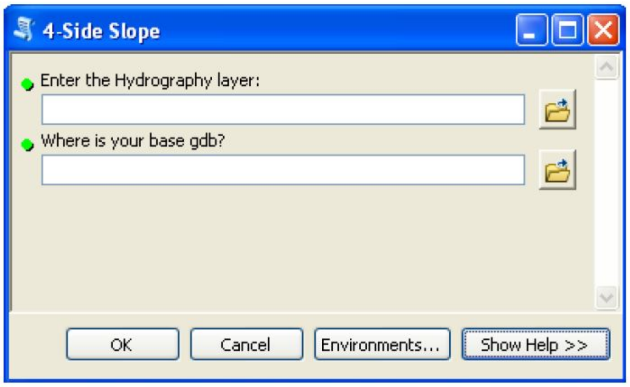
Note: If the results show a lot of -999 values, the transect length may have been set too short. Try re-running the transect script tool with a larger length value.

Note: For Channel Belt ONLY, if a segment has a result of -999, it may mean there is no channel belt at that point.

Note: No channel belt values will be calculated if a channel belt data layer was not specified in tool 1.

5.2.4 Side slope

1) ► Click **4-Side Slope** in the **RESonate Toolbox**. This script tool will calculate the left and right side slopes of the river valley. The required fields are automatically populated. The results will be added to the Left Valley Slope and Right Valley Slope fields in the Master Table.



Note: This tool uses results from preceding scripts, script tools 1-3 must be run before running this script tool.

5.2.5 River sinuosity

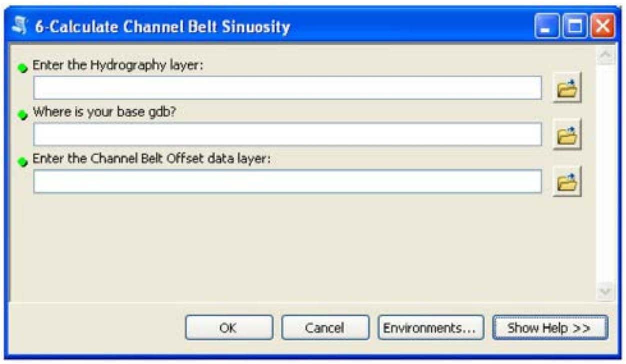
1) ► Click **5-Calculate River Sinuosity** in the **RESonate Toolbox**. River channel sinuosity is calculated by dividing the true river length between two sampling points by the straight line distance between those same points. The results are added to the SinuRC (sinuosity of river channel) field in the Master Table. The required fields are automatically populated.

Note: Sinuosity values calculated by this tool are **ONLY accurate in straight valleys** where down valley distance is approximates inter-point distance. This becomes less likely as the user-defined sample distance increases. Procedures for producing accurate river channel sinuosity in sinuous valleys are outlined after the channel belt sinuosity instructions in Section 5.6.

5.2.6 *Channel belt sinuosity (optional)*

This script tool calculates the sinuosity of the channel belt. This tool only needs to be run if the river system has a channel belt. The results are added to the Master Table in the database created in Step 2 of section 5.2. Sinuosity is calculated by dividing the length of the channel belt between two sampling points by the straight line distance between the same sampling points. The script tool references the text file produced in the first script tool to automatically populate the required variables.

1) ► Click **6-Channel Belt Sinuosity** in the **RESonate Toolbox.** The required data inputs will be automatically populated.



Note: As with river channel sinuosity, the channel belt sinuosity values calculated by this tool are **ONLY accurate in straight valleys** where down valley distance is approximates inter-point distance. Procedures for producing accurate river channel and channel belt sinuosities are outlined below.

Calculating river sinuosity in sinuous valleys

There are several procedures that can be used (interchangeably) to correct RESonate sinuosity values: smoothing distance and manual calculation.

1) ► Use ArcCatalog to navigate to **"X" River Typing » 09 GDB**. Open the GDB and expand the **Smoothing** dataset generated by the **Transect Generation** tool. Each stream will be associated with several smoothed line files (each containing the name of the stream and the simplify factor used in smoothing). Lines named **"Stream name_smooth_"simplify factor"_split2** contain the information needed, add all of these to ArcMap.

2) ► Add **"X"_DEM** to the map and check to see if each smoothed line is a good approximation of down valley (DV) distance. There will almost always be some portions of the smoothed line that do not approximate DV distance, manual calculations can be used in these situations.

3) ► If a majority of the smoothed lines approximate DV distance, use the **Merge** tool in **Data Management Tools** to merged all smoothed lines into a single file named "**X"_smooth_split2** in the **"X" River Typing » 09 GDB** folder.

4) ► Add the **Master Table** to ArcMap. Select the **Data Management Tools » Joins » Join Field** tool from **Arc Toolbox.** Set **Input Table** as the **Master Table** and **Input Join Field** as **SegID**. Set **Join Table** to "**X"_smooth_split2** and **Output Join field** to **SegID**.

Set the optional **Join Fields** to **Shape_Leng** and hit **OK**. When the tool completes the join, open the **Master Table** and change the alias of the newly joined **Shape_Leng** field to **DV_Dist**.

5) ► Start editing the **Master Table**. Use the **Measure** tool to manually measure and replace any **DV_Dist** value inaccurately estimated by "**X"_smooth_split2**.

6) ► Add a field named **R_Sin_Cor** to the **Master Table** and set it as **Double**. Use **Field Calculator** to divide the user defined sample distance by **DV_Dist**.

<u>Calculating channel belt sinuosity in sinuous valleys</u>

1) ► Sinuosity is calculated for both sides of the channel belt, but only one side will be used in later statistical analysis. Randomly select a side and record the choice in the **"X"_Notes and Settings** file.

2) ► Use ArcCatalog to navigate to **"X" River Typing » 09 GDB**. Open the GDB and expand the **CBSinuosity** dataset. Add either **cb_split_L** or **cb_split_R** to ArcMap.

3) ► Add a field named **SegID** to **cb_split_"X"** and set it as **Text** with a **50** character limit. Use **Field Calculator** to set **SegID = SegID_Up**.

4) ► Use the **Join Field** tool to add the **SHAPE_Length** field in **cb_split_"X"** to the **Master Table**. Once added, change **SHAPE_Length**'s alias to **"X"_cb_leng**.

5) ► Add a Field named **"X"_CB_Sin_Cor** and set it as **Double**. Use **Field Calculator** to divide **"X"_cb_leng** by **DV_Dist**.

5.2.7 Channel planform

Channel planform (PLN) is a description of river channel form as viewed from above. This variable currently requires visual interpretation of satellite/aerial photographs taken during periods of sub-bankfull discharge. A generalized categorical classification for river planform is used to describe planform. The classification is based on the number of channels and the number and density of channel-islands. The categories described below are based on the planform diversity observed in a number of study watersheds. These categories are not meant to encompass all possible planform types. Additional categories may be added if unique planform types are observed in other watersheds.

Planform categories:

Single channel - The entire sample segment consist of a single channel throughout its entire length

Multi-channel, low island density - The sample segment has at least one primary and one secondary channel divided by a relatively large, isolated channel island. Multiple islands may exist within a single sample segment, but they must be separated by relatively long river-distances and, therefore do not form tertiary channels.

Multi-channel, high island density - A segment classified as 3 has a braided character with a high density of channel islands splitting the main channel into secondary and tertiary channels in at least one location within a sample segment.

Reservoir - Segments are classified as reservoir if at least 25% of their length is judged by the user to be part of an impoundment.

<u>To add Planform</u>:

1) ► Load the **Master table** and **sitelocations** from the geodatabase into ArcMap and start editing the Master table.

2) ► Add the satellite/aerial photographs from the source established during the data collection phase. Classify the planform of each sample segment and manually populate the Planform field with the appropriate planform number.

Note: A common map scale should be used for all planform classifications. We typically use a map scale of 1:25,000 because it's possible to view and assess a 10-km long sample segment in its entirety on a wide-screen 24” computer monitor.

5.3 Optional Manually Calculated Variables

5.3.1 Valley sinuosity

Valley sinuosity is a simple measure of valley curvature. It can be obtained by dividing a down valley distance value (determined in the river sinuosity step) by the straight-line distance between the upstream and downstream sampling points of each segment.

1) ►Add the Master table to ArcMap, add a field named **Val_Sin**, and set the field as **Double**.

2) ►Use ArcCatalog to navigate to **"X" River Typing » 09 GDB**. Open the GDB and expand the **RiverS** dataset. Locate the file named **RiversSinuosity_split"#"m** and add it to ArcMap.

3) ►Use the Join tool to join the **StrDist** (the straight line distance between two sample points) to the **Master Table**. Use the **Seg_ID** field to accomplish the join.

4) ►Use the Field Calculator to populate the **Val_Sin** field. Divide **DV_Dist** by **StrDist**.

5.3.2 Bankfull width

Bankfull width (BFW) is defined as the width of the active river channel at the point where over-bank flow begins during a flood event. BFW forms the basis for many hydrogeomorphic metrics. There are numerous methods for calculating BFW, but the method best suited to our hydrogeomorphic analysis is measurement via aerial/satellite photograph interpretation.

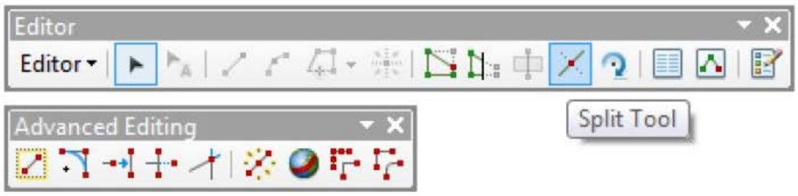
1) ► **Export** the **Transect_Simple** feature class from the file geodatabase generated by RESonate and name it **BFW_Transects**. Export the file to the **"X" River Typing » 09 GDB** folder.

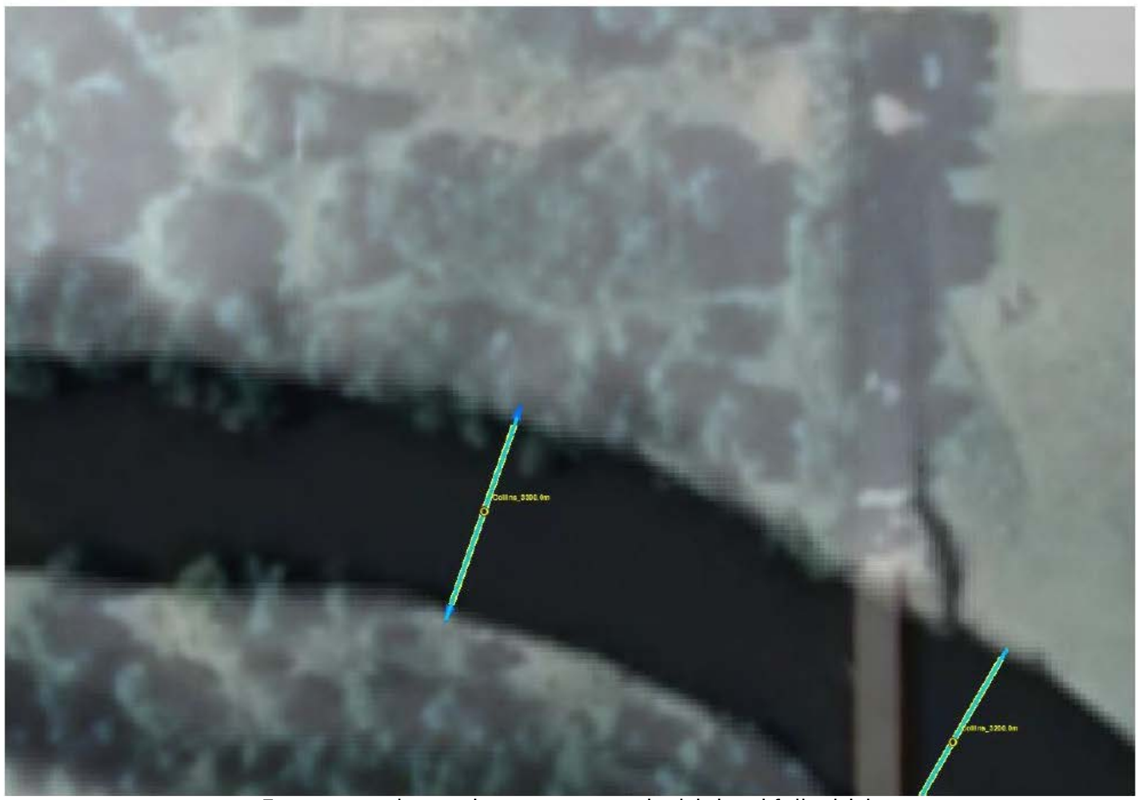
Note: You can also use RESonate to generate sample transects that are perpendicular to the river channel (set the simplify factor to 0.01). Be sure to save the new GDB in a different location than the GDB containing the data extracted by RESonate. The original GDB may be overwritten if the BFW GDB is not saved to a separate location.

2) ► Add the **BFW_Transects, "X"_DEM**, and the satellite/aerial photograph source to ArcMap.

3) ►Use the **Dissolve** tool to dissolve transects by **SegID's**. This will eliminate the left and right side attribute. **Save** the new file as **BFW_Transects_dis**.

4) ► Start editing **BFW_Transects_dis**. Ensure that each sample transect is perpendicular to the river channel. Use the **Split tool** in the **Editing** toolbar to trim each transect at its left and right bankfull location. Select and delete the non-bankfull portions of each transect.





Transects trimmed to correspond with bankfull width

Note: Judgments about bankfull width are best made while viewing the DEM and aerial photos at the same time. Set the display properties of the aerial photos so they are transparent enough to see the underlying DEM.

5) ► Add a field named **BFW** to **BFW_Transects_dis** and set it as **Double**. Use **calculate geometry** to calculate the length of the BFW transects.

6) ► Use the **Join Field** tool to join the **BFW** field to the **Master Table**. Use **SegID** to accomplish the join.

5.3.3 Valley floor width to bankfull width ratio

This ratio can help distinguish sections that have similar valley floor widths but different channel widths, and therefore, vastly different upstream influences, habitat, etc.

1) ► Add a field to the **Master Table** named **VFW_BFW** and set it as **Double**. Use the **Field Calculator** to divide the **VFW** field by the **BFW** field.

6. References

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7. Appendix

7.1 FPZ Streamline Creation & Categorization

► Visualizing FPZ Streamlines and Sample Sites

1. ► Export the table with the final FPZ grouping decisions from the statistical software in CSV format as **“X”_Master_Groups.csv**
2. ► Import into ArcGIS
3. ► Load **RiverSinuosity_split”#”m** (# refers to sample length) from the RESonate database **“X”_Streamlines.gdb » RiverS**
4. ► Join the **“X”_Master_Groups** table to the **RiverSinuosity_split”#”m** attribute table using Segment IDs (or Seg_ID)
5. ► Save the joined **RiverSinuosity_split”#”m** as **“X”_River_FPZs.shp** (polyline)
6. ► Load **“X”_River_FPZs.shp**

The same process can be used to display coded sample points by switching out the **RiverSinuosity_split”#”m** file for the **sitelocations_SpatialJoin** file in the RESonate database.

Line segments color coded by FPZ group

Sample points color coded by FPZ group

► FPZ Category Examples

The following groups are examples of hydrogeomorphic attributes used to summarize statistical groupings of river segments based on data from the **Kanawha River**.

Lowland Alluvial Zone
<u>Key Characteristics:</u>
- Alluvial geology
- Low elevation
- Wide valley floors and lateral floodplains
- Low ratio of valley width to valley floor width
- Relatively steep valley side slopes
- Low down valley slope
- Typically a low sinuosity single channel system with occasional anabranching due to large permanent islands

Lowland Constricted Zone
<u>Key Characteristics:</u>
- Bedrock geology
- Low elevation
- Relatively narrow valleys
- Narrow valley floor
- High ratio of valley width to valley floor width
- Steep valley side slopes
- Moderate down valley slope
- Typically a low sinuosity single channel system with occasional anabranching due to permanent islands

Constricted Upland Zone
<u>Key Characteristics:</u>
- Bedrock geology
- High elevation
- Relatively narrow valleys
- Narrow valley floor
- High ratio of valley width to valley floor width
- Relatively steep valley side slopes
- Moderate down valley slope
- Typically a low sinuosity single channel system with occasional anabranching due to occasional small islands (more frequent than group 2)

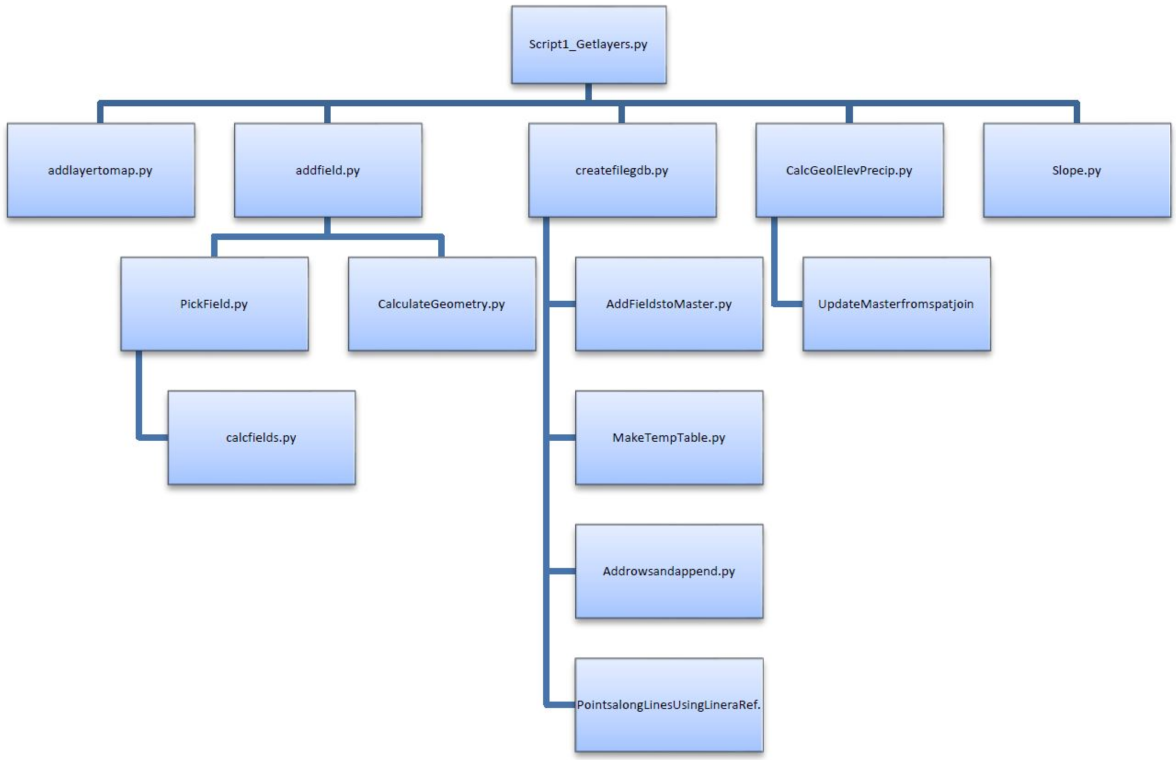
Open Valley Upland Zone
<u>Key Characteristics:</u>
- Bedrock Geology
- High Elevation
- Very wide valleys
- Relatively wide valley floor
- Relatively lower ratio valley width to valley floor width
- Low valley side slopes
- Steep down valley slope
- Typically a moderate sinuosity single channel system with occasional anabranching due to small islands (more frequent than group 2)

Constricted High Energy Upland Zone
<u>Key Characteristics:</u>
- Bedrock geology
- High elevation
- High mean annual precipitation
- Relatively narrow valleys
- Very narrow valley floors
- High ratio of valley width to valley floor width
- Relatively steep valley side slopes
- Steep down valley slope
- Predominately a single channel system (small islands possible but very rare)

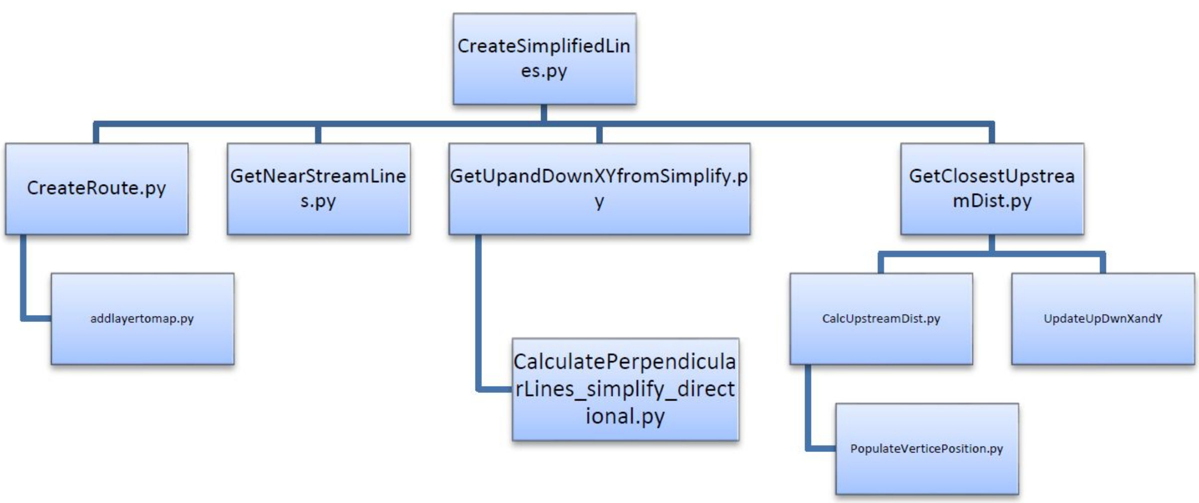
Reservoir / Waterfall
<u>Key Characteristics:</u>
- Waterbody

7.2 RESonate toolbox scripts

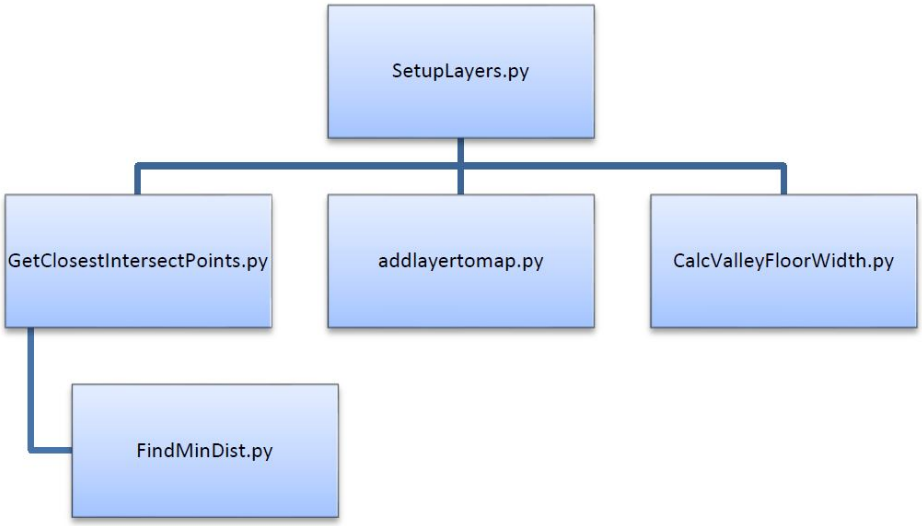
1 – RESonate Analysis Tool - Start



2 – Generate Transects



3 – Calculate Widths



4 – Calculate Channel Belt Sinuosity