

Standard Operating Procedure 1.2.15

Wadeable Stream Basin- and Segment-scale Data

Summary—Version 1.0

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Summary

The following standard operating procedure (SOP) outlines the procedure for calculating basin and segment-scale data for the sample reaches chosen as part of the SECN wadeable stream protocol. The purpose of this SOP is to ensure that basin- and segment-scale variables are calculated using the same methods and techniques, which will allow watersheds to be compared within and between parks. The characteristics calculated in this SOP are suggested by the United States Geological Survey (USGS) National Water-Quality Assessment (NAWQA) Stream Habitat Characterization Methods manual (Fitzpatrick et al. 1998) and tailored to target the objectives of the SECN stream habitat assessment and characterization protocol. This SOP assumes the user has at least an intermediate understanding of geographic information systems (GIS) and can use the statistical software R.

Revision Log

[illegible]

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Required Materials

- Desktop or laptop computer running ArcGIS 10.x* with Spatial Analyst extension
- “Watershed Characteristics” ArcToolbox
- Point coverage of sample reaches (shapefile)
- 10-meter (32.8-feet [ft]) digital elevation model (DEM) of study area
- National Land Cover Database (NLCD) datasets
- R statistical software*

*Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

Basin and segment scale characterization

The measurements and analyses described in this SOP utilize a geographic information system (GIS) along with datasets that are readily available from states, municipalities, and federal agencies. This SOP describes the methods that should be followed to calculate basin- and segment-scale characteristics for each study reach from a 10-meter (32.8-ft) DEM. Many of the basin- and segment-scale characteristics described in this SOP are suggested by Fitzpatrick et al. (1998). Additional measures of basin morphology (standard deviation of elevation, average slope, standard deviation of slope, and bifurcation ratio) are added to the characteristics suggested by Fitzpatrick et al. (1998) to help provide additional understanding of basin characteristics that have been shown to influence storm runoff and peak flows (McDonald et al. 2018a).

Basin land use/land cover (LULC) needs to be updated every other reach survey (every six years), dependent on whether a new coverage is available. These LULC metrics will be calculated and reported to the parks along with the other basin characteristics to help develop an understanding of the geomorphic and anthropogenic drivers of stream habitat variability. This SOP describes the methods to determine LULC from the National Land Cover Dataset (NLCD). To calculate additional land cover and population variables, refer to the NPScape SOPs (NPS 2016).

The following parameters should be calculated for each reach:

- **Drainage area** refers to the area within which precipitation, sediment, and dissolved constituents are funneled to a common outlet point (Dunne and Leopold 1978).
- **Total upstream perennial stream length** is the length of all perennial streams that flow to a common outlet.
- **Drainage density** is the ratio of total perennial stream length to drainage area.

- **Basin shape** is calculated by dividing basin area by basin length squared. Basin length refers to the length of a line running from outlet to drainage divide that bisects the watershed.
- **Basin Relief** is the maximum amount of relief (maximum elevation minus minimum elevation) found within the basin.
- **Basin Relief Ratio** is calculated by dividing basin relief by basin length.
- **Standard Deviation of Elevation** is the standard deviation of elevation within the basin.
- **Slope** will be characterized by determining the average and standard deviation of slope within the watershed.
- **Entire Stream Gradient** is calculated by determining the difference in elevation at 85% and 10% of the main stem stream length divided by the stream length between the two points.
- **Segment Gradient** is the difference in the upstream elevation of the stream segment minus the downstream elevation of the stream segment divided by the length of the stream segment.
- **Stream order** classifies streams based on the number and character of their tributaries (Strahler 1957). This SOP describes how to determine Strahler stream orders.
- **Bifurcation ratio** is the ratio of the number of streams in a given Strahler order to the number of streams in the next highest order (e.g., number of first order streams/number of second order streams). An average watershed bifurcation ratio can be determined by adding these individual ratios and dividing by the highest stream order minus one.
- **Land Use/Land Cover** will be calculated from the most recent NLCD dataset. This dataset classifies land cover using a modification of Anderson et al. (1976).

For more details regarding basin- and segment-scale characterization, the reader is referred to Fitzpatrick et al. (1998) and *Monitoring Wadeable Stream Habitat Conditions in Southeast Coast Network Parks: Protocol Narrative* (McDonald et al. 2018b).

Procedure

The following procedures outline how to calculate the basin characteristics listed above using ArcMap 10.x. Words in italics refer to ArcMap tools. If you can't find the tools in the ArcToolbox, use the Search tab. All data will be stored on the SECN GIS drive. For detailed data management instructions see SOP 2.2.13 *Wadeable Stream Data Entry and Storage—Version 1.0* (McDonald et al. 2018c).

The procedures outlined in this SOP use a 10-meter (32.8-ft) DEM. Using a DEM with different resolution will provide a different value for many if not all of the metrics outlined in this SOP. Use a consistent DEM resolution with all reaches that are to be analyzed. Unless a new digital elevation model (DEM) is used, many if not all of rasters/coverages will have already been derived. Check the SECN GIS drive:\GIS\projects\StreamHabitat\Wadeable\PARK\Data\Basin folder prior to running any of the following tools.

Watershed Characteristics

The *Watershed Characteristics* toolbox will be used to calculate the majority of the metrics mentioned above. The toolbox can be found on the SECN GIS drive: \GIS\projects\StreamHabitat_toolbox. For more information on how the tools were derived and the layout of these models see Appendix A.

Prior to calculating the basin characteristics for each stream reach, a 10-meter (32.8-ft) DEM needs to be obtained (one source is the [USDA data gateway](#)).

****NOTE:** Ensure the DEM is projected in UTM (Figure 1) prior to following any of the steps in this SOP. If any of the files are not in the correct projection, run *Project Raster* (Figure 2):

1. Input Raster => DEM;
2. Output Raster Dataset => DEM_pro;
3. Output Coordinate System => NAD 1983 UTM Zone ##N

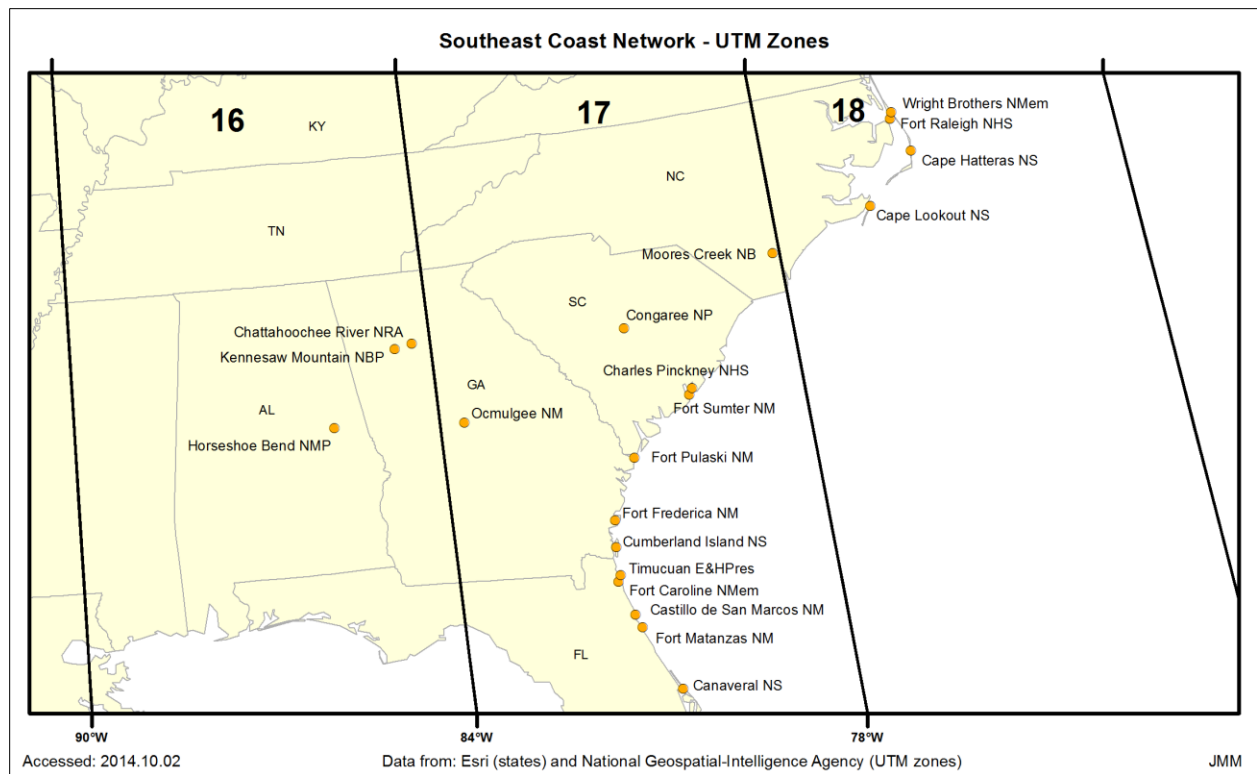


Figure 1. UTM zones for the parks in the Southeast Coast Network.

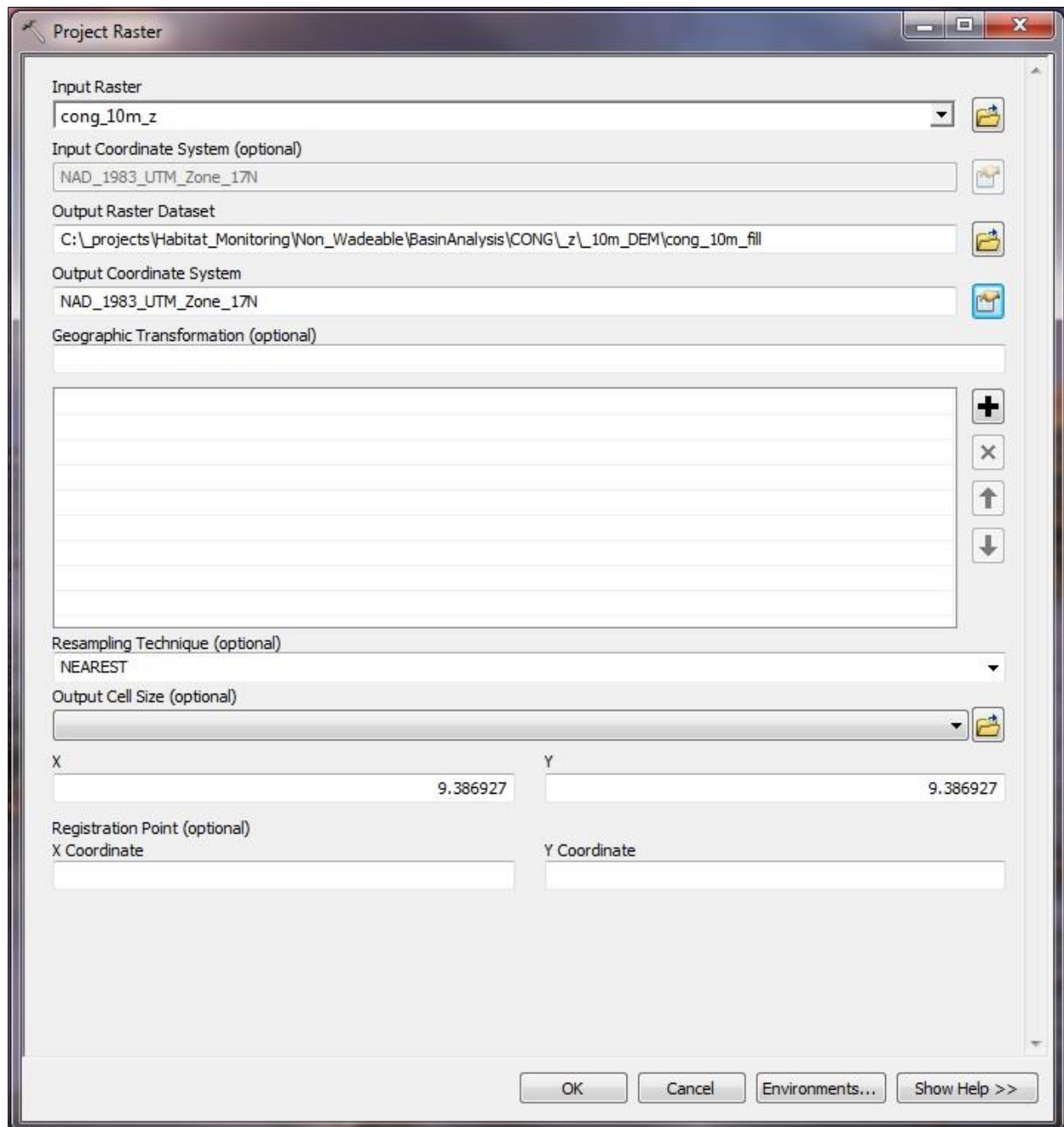


Figure 2. Project Raster options.

Once the 10-meter (32.8-ft) DEM is obtained and is checked to make sure it is projected in the required UTM zone, run the first tool in the Watershed Characteristics toolbox, *1-Flow Characteristics* (Figure 3).

This tool will create Flow Direction and Flow Accumulation rasters that are needed to run the rest of the tools in the Watershed Characteristics toolbox. Additionally, this tool will also create a 20-

hectare (2.5-acre [ac]) flow accumulation-threshold stream network that will also be needed to calculate some of the variables below.

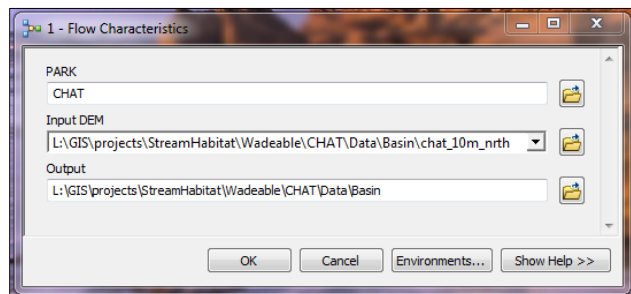


Figure 3. Dialog box for the 1 - Flow Characteristics tool.

The output for this tool should be:

SECN GIS drive:\GIS\projects\StreamHabitat\Wadeable\PARK\Data\Basin

Drainage Area (DA)

In order to determine drainage area, the outlet of the basin (reach location) must be associated with a flow accumulation raster. A shapefile of the sample reach(s) (PARK### or PARK_wadeable_sites.shp) will be in the PARK\Data folder.

Make a copy of the PARK_wadeable_sites.shp and name it PARK_wadeable_sites_out.shp. These points need to be associated with the stream network that was derived from the flow accumulation raster. To do this, start an editing session and for each reach, zoom in and manually move each point to a PARK_acc stream pixel (white pixel). Depending on the size of the stream, you may need to change the display options (current display extent) to determine the location of the network (Figure 4). Use the PARK_20ha_stream.shp dataset and zoom in on each reach to determine the closest flowline (Figure 5).

Once the outlet points have been associated with the flow network, export each 'out' point to its site (reach) folder on the SECN GIS

drive:\GIS\projects\StreamHabitat\Wadeable\PARK\Data\Site\PARK### and name the point PARK###_out.shp. Each reach's watershed can now be delineated using the second tool in the Watershed Characteristics toolbox, 2 - *Watershed Delineation* (Figure 6).

When the tool is done running, check the watershed to make sure that the entire 20-hectare (2.5-ac) stream network upstream of the outlet point is contained within the reach's delineated watershed. If the watershed is correct, add a field named 'DA_km' and calculate the drainage area in km².

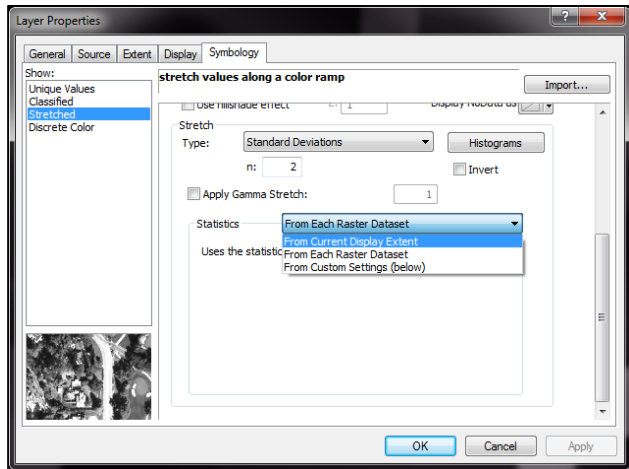


Figure 4. How to reclassify stretched raster data so that only the current display extent is used.

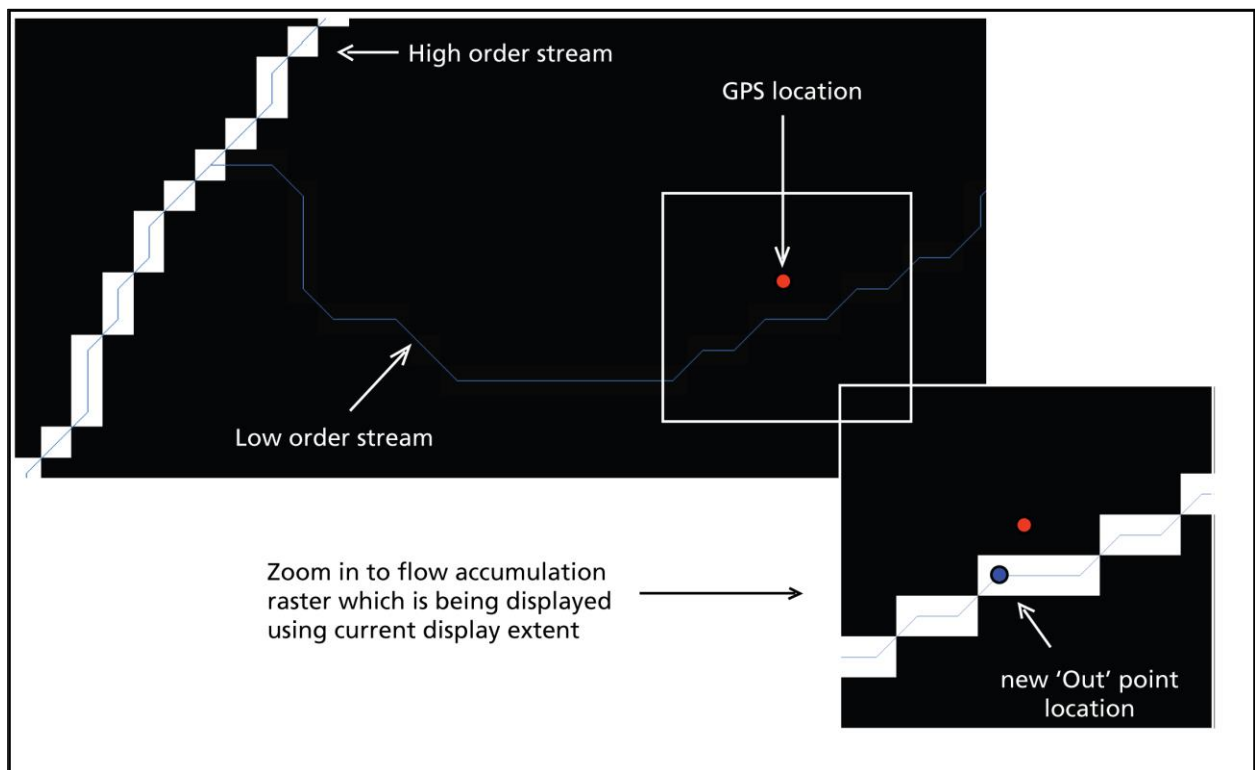


Figure 5. Example showing the data that should be used to properly place the 'outlet' points on the flow accumulation raster. Need to zoom in to see the smaller stream because the flow accumulation values of the high order stream are at least an order of magnitude larger than the lower order stream.

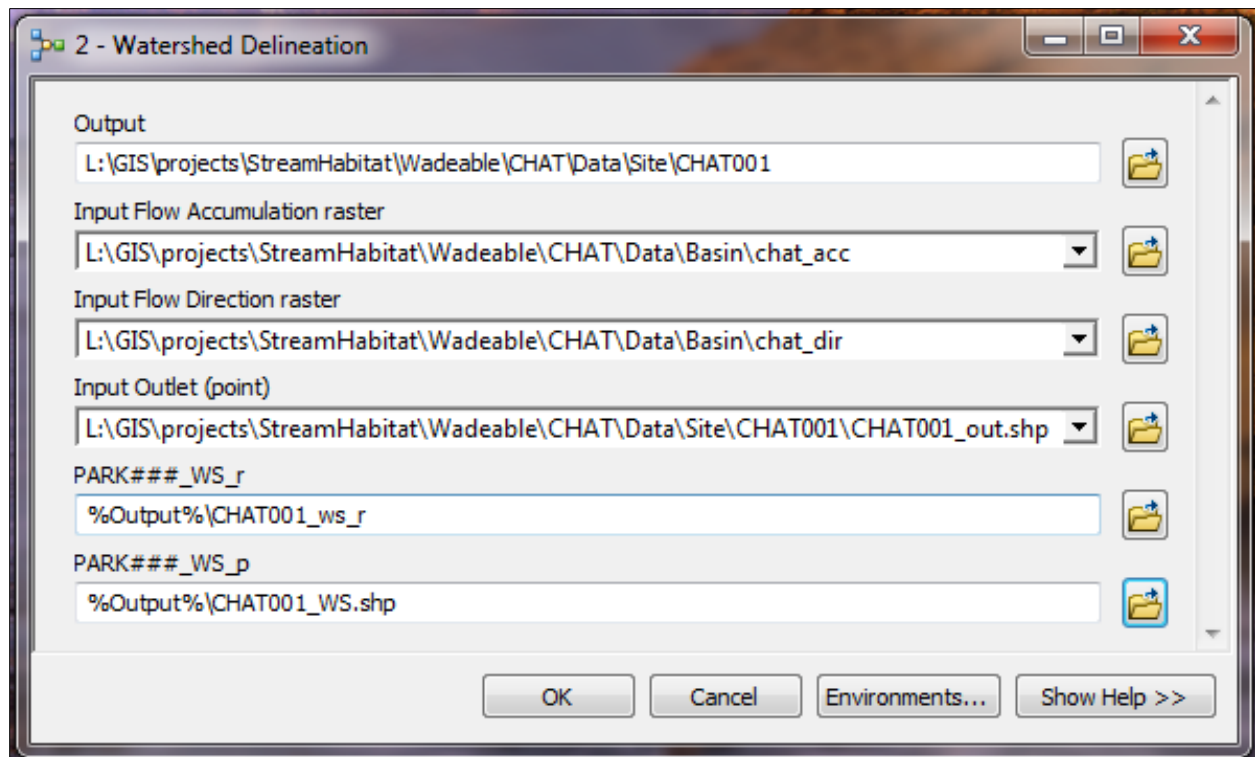


Figure 6. Dialog box for the 2 - *Watershed Delineation* tool.

Total Upstream Perennial Stream Length (TSL)

Prior to determining the TSL for each reach, make sure the previous sections were completed and each reach's watershed has been delineated.

Once the watersheds have been created and checked, the 20-hectare (2.5-ac) flow accumulation-threshold stream network will be used to calculate the TSL for each drainage basin. The *Clip* (*Analysis Tools*) tool will be used to create each reach's watershed's stream network (Figure 7).

- Input Features => PARK_20ha_streams.shp,
- Clip Features => PARK###_WS.shp;
- Output Feature Class => PARK###_20ha_streams.shp
- (output to Data\Sites\PARK### folder)

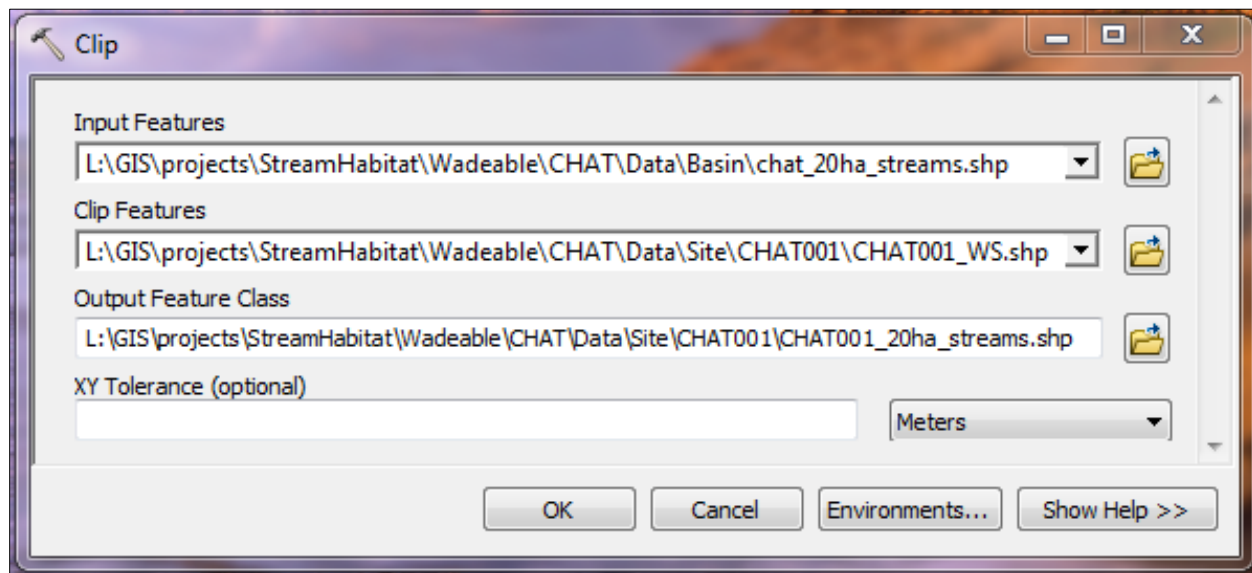


Figure 7. *Clip* settings.

Once the streams have been clipped to each watershed, add a field in the attribute table of each clipped stream network called “Length_km” (Type => Double). Right-click the “Length_km” field and use the Calculate Geometry option to calculate the length of each segment in kilometers.

Now that the streams have been attributed with their lengths (in kilometers), add a field to the *PARK###_WS.shp* named “Length_km” and attribute this field with the sum of the “Length_km” field from the clipped NHDplus feature class.

- In the *PARK###_20ha_streams.shp* attribute table, right-click on the “Length_km” field and select “Statistics” to determine the sum of the stream lengths.

Drainage Density (DD)

Once DA and TSL have been calculated, add a field to the *PARK###_WS.shp* named “DD_km” and calculate DD by dividing “TSL_km” by “DA_km.”

Basin Length (BL)

Basin length (BL) is needed to calculate basin shape, the basin relief ratio, and the entire stream gradient. This SOP will approximate BL by determining the maximum flow length from outlet to drainage divide. Use tool 3 – *Upstream Flow Length*, in the *Watershed Characteristics* toolbox, to calculate the maximum flow length within the study reach’s watershed.

When using the *Upstream Flow Length* tool, be sure to check the box that makes the tool clip the input Flow Direction raster to the extent of the watershed or the Flow Length raster will be incorrect (Figure 8). This tool clips the input Flow Direction raster to the extent of the input Watershed, runs the *Flow Length* tool, and then divides the output raster by 1,000 to convert from m to km (Figure A-3).

Once the Upstream Flow Length raster has been created, use the *Identify* tool in ArcMap to determine the value of the cell beneath the outlet point and add this value to a new field (BL_km, TYPE - Double) in the PARK###_WS.shp.

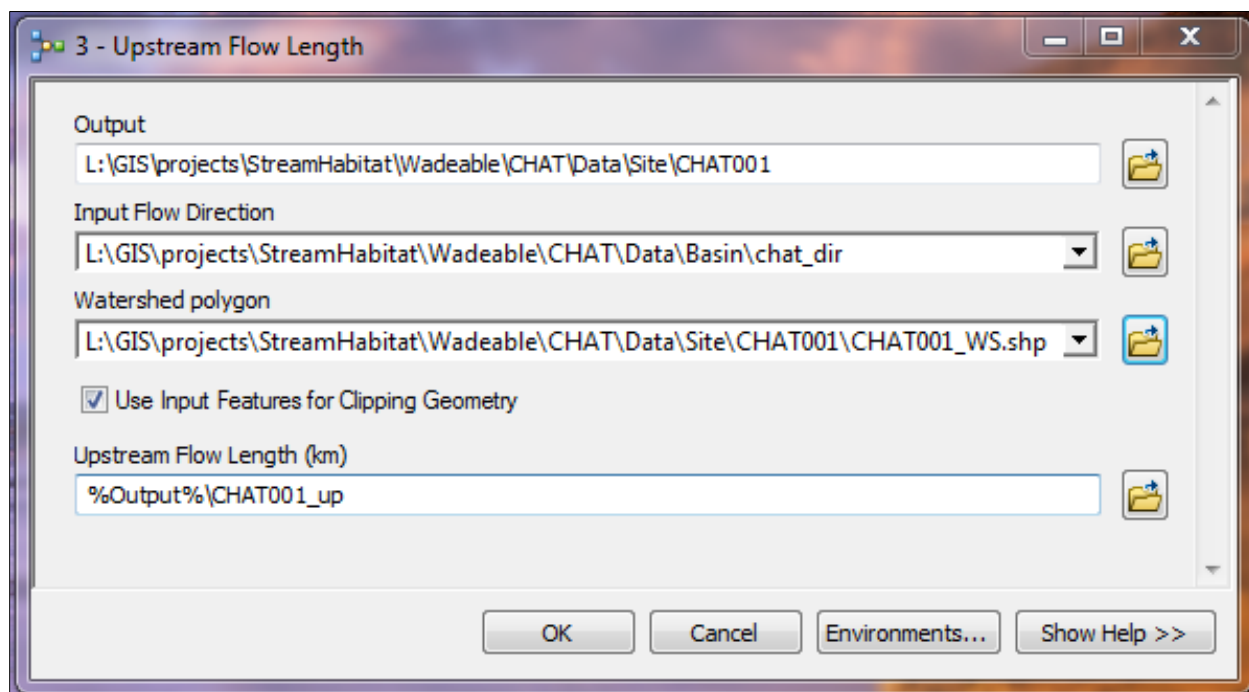


Figure 8. Dialog box for the *Upstream Flow Length* tool

Basin Shape (BS)

Once BL has been calculated, add a field to the PARK###_WS.shp called BS_km, and use the field calculator to divide DA by BL² and calculate BS.

Basin Relief (BR), Basin Relief Ratio (BRR) and Slope (aSlope and sdSlope)

Basin relief (BR), the standard deviation of watershed elevation (zSD), average watershed slope (aSlope), and the standard deviation of watershed slope (sdSlope) are all calculated by using the fourth tool in the Watershed Characteristics toolbox (4 - *Basin Relief and Slope*). The inputs that are needed to run this tool are the Output (site) folder, an input watershed raster, an input DEM (not hydro-corrected), and an input Slope raster (use the *Slope* tool if one hasn't already been created) (Figure 9).

This tool uses the zonal statistics tool to determine the maximum and minimum elevation values within a watershed and then calculates BR by determining the difference between the two (Figure A.4). The *zonal statistics* tool is also used to determine aSlope and sdSlope.

Once the tool has been run, add fields for each of the variables that were just calculated (aSlope, sdSlope, BR_km, sdZ_km). Make each of the fields DOUBLE and attribute them with the value of each exported raster.

After all of the above variables have been attributed to the PARK###_WS.shp, add a field (DOUBLE) named “BRR” and calculate the basin relief ratio by dividing basin relief (BR) by basin length (BL).

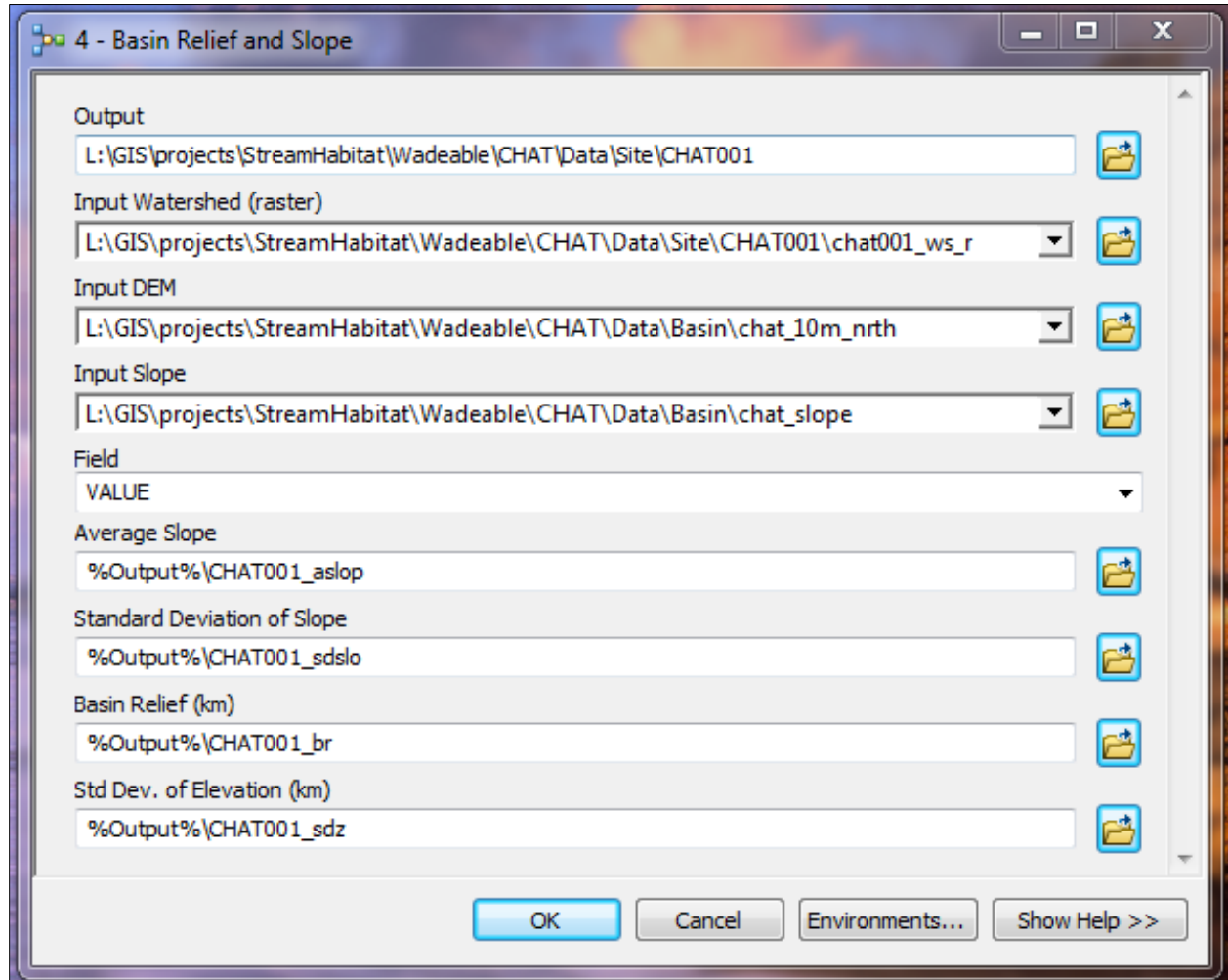


Figure 9. Dialog box for 4 – Basin Relief and Slope

Entire Stream Gradient (ESG)

The entire stream gradient (ESG) is calculated by determining the difference in elevation between points on the main stem stream network that are 85% and 10% upstream of the watershed outlet. The first step is to create a new shapefile in the Data\Sites\PARK folder named PARK###_ESG_pts. Add this shapefile to an ArcMap document along with the Basin Length raster and the clipped 20-hectare (2.5-ac) stream network.

The next step is to determine the flow length that corresponds to 85% and 10% upstream from the watershed outlet (e.g., if maximum Basin Length equals 1 km, 85% = 0.85 km and 10% = 0.10 km). Manually find the pixels on the flow length raster that are closest to these distances (along the main

stem) and place points there. After the points have been placed, determine their elevations from the (un-hydrologically-corrected) DEM.

Using these elevations, calculate ESG by dividing the difference in elevations (be sure to convert to kilometers) by the stream length between. Add a field to the PARK###_WS.shp named ESG (DOUBLE) and attribute this field with the calculated ESG.

Segment Gradient (SG)

A shapefile containing the 20-hectare (2.5-ac) stream network for each watershed is needed to complete this section. If the stream network has not been created, see the Total Stream Length section above.

To calculate segment gradient, simply determine the difference in the upstream elevation of the stream segment and downstream elevation of the stream segment, convert to kilometers, and then divide by the length of the stream segment.

Stream Order (SO)

A shapefile containing the 20-hectare (2.5-ac) stream network for each watershed is needed to complete this section. If it has not yet been made see the Total Stream Length section above. The stream network is attributed with the Strahler stream order (field labeled “GRID_CODE”) of each stream.

The first step is to add a field in the PARK###_WS.shp named “Strahler” (Type: Short Integer). Add the stream network to ArcMap, select the stream that is closest to the outlet point, and add the “GRID_CODE” to the “Strahler” field that you just added to PARK###_WS.shp.

Bifurcation Ratio (BiR)

This section will also use the clipped 20-hectare (2.5-ac) stream network so, again, if this shapefile has not yet been created, go back to Total Stream Length section and follow the required steps.

The bifurcation ratio can be calculated by determining the ratio of the number of streams in each order to the number of streams in the next highest order. An average bifurcation ratio is calculated by adding up all of the bifurcation ratios and dividing by the maximum stream order minus one. If the stream is a first order stream, the use ‘1’ as the BiR. Once the BiR has been calculated, add a field to the PARK###_WS.shp named “BiR” (Type: DOUBLE) and add this value.

Once all of the basin characteristics have been calculated, export the PARK###_out feature class attribute table to S:\Monitoring\StreamHabitat\Wadeable\Data\PARK\A_RawData and name it PARK###_BasinCharacteristicsYYYYMMDD.txt (date at end of file should be date that the data were exported).

Land Use/Land Cover (LULC)

This section describes the methods that should be used to determine the land use/land cover (LULC) for each watershed. In order to complete this section, the study reach’s watershed needs to have been

delineated and the National Landcover Database (NLCD) coverages for the years that are to be characterized need to be acquired.

The land cover data can be found on the SECN GIS drive at the following location:

SECN_GIS_drive:\GIS\state_regional_gis\data\basedata\landcover or downloaded from the NLCD website. The *Zonal Histogram* tool will be used to determine the number of pixels that are classified as each land cover type within the input watershed.

- *Zonal Histogram* (Figure 10):
 - a. Input raster or feature zone data => PARK###_WS.shp
 - b. Zone field => Id
 - c. Input value raster => NLCD_YYYY
 - d. Output table => PARK###_LULC_YYYY.dbf

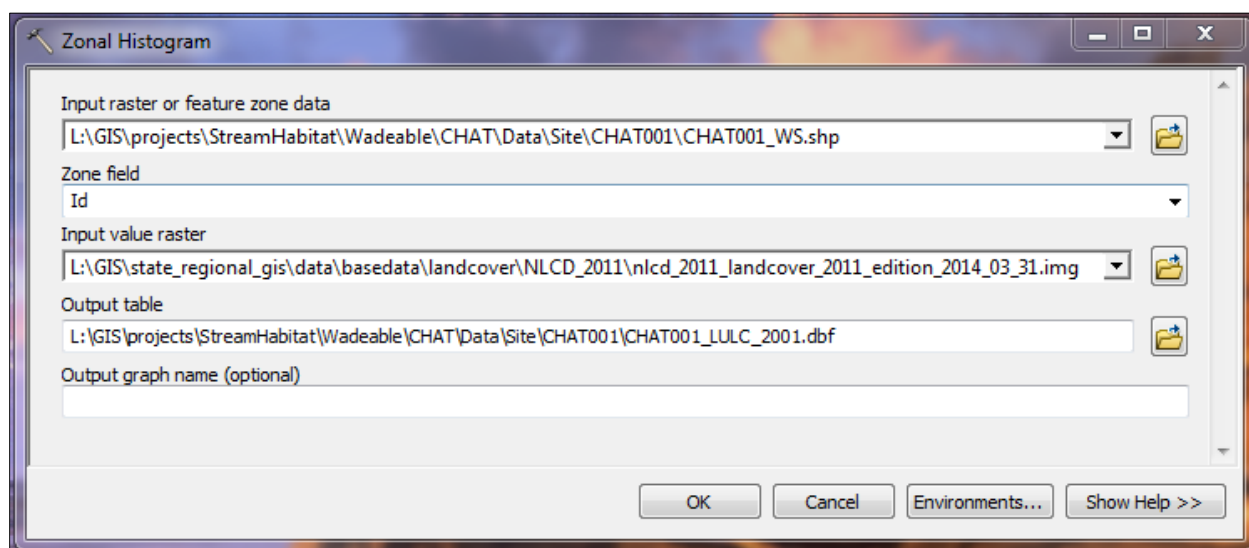


Figure 10. *Zonal Histogram* settings.

After all of the tables are created, use ArcCatalog to export the data (as .txt) and save them onto the SECNshare drive: \\Monitoring\StreamHabitat\Wadeable\Data\PARK\A_RawData\PARK###. Name them PARK###_LULC_YYYY.txt.

Use the R code found in Appendix B or on the SECNshare:

\\Monitoring\StreamHabitat\Wadeable\Code (named Combine_LULC_YYYYMMDD.r). You will need to change the site and survey.date objects to reflect the reach and survey that is being analyzed, and you may also need to add additional lines to read in and process any additional years.

Once the LULC data have been processed and combined using the R code, see SOP 2.2.14—*Wadeable Stream Data Processing and Analysis—Version 1.0* (McDonald et al. 2018d) for instructions on how to turn these data into report ready tables.

Literature Cited

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- McDonald, J. M., E. N. Starkey, and M. B. Gregory. 2018d. Wadeable stream data processing and analysis. Southeast Coast Network Standard Operating Procedure NPS/SECN/SOP—2.2.14. National Park Service, Athens, Georgia. Available at <https://irma.nps.gov/DataStore/Reference/Profile/2254015> (last accessed July 2018).
- National Park Service. 2016. NPScape: monitoring landscape dynamics of US National Parks. Natural Resource Program Center, Inventory and Monitoring Division. Fort Collins, Colorado. Available at: <https://science.nature.nps.gov/im/monitor/npscape/methods.cfm> (last accessed May 2017).
- Strahler, A. N. 1957. Quantitative analysis of watershed geomorphology. Transactions, American Geophysical Union 38:913–920.

Appendix A. Watershed Characteristics toolbox

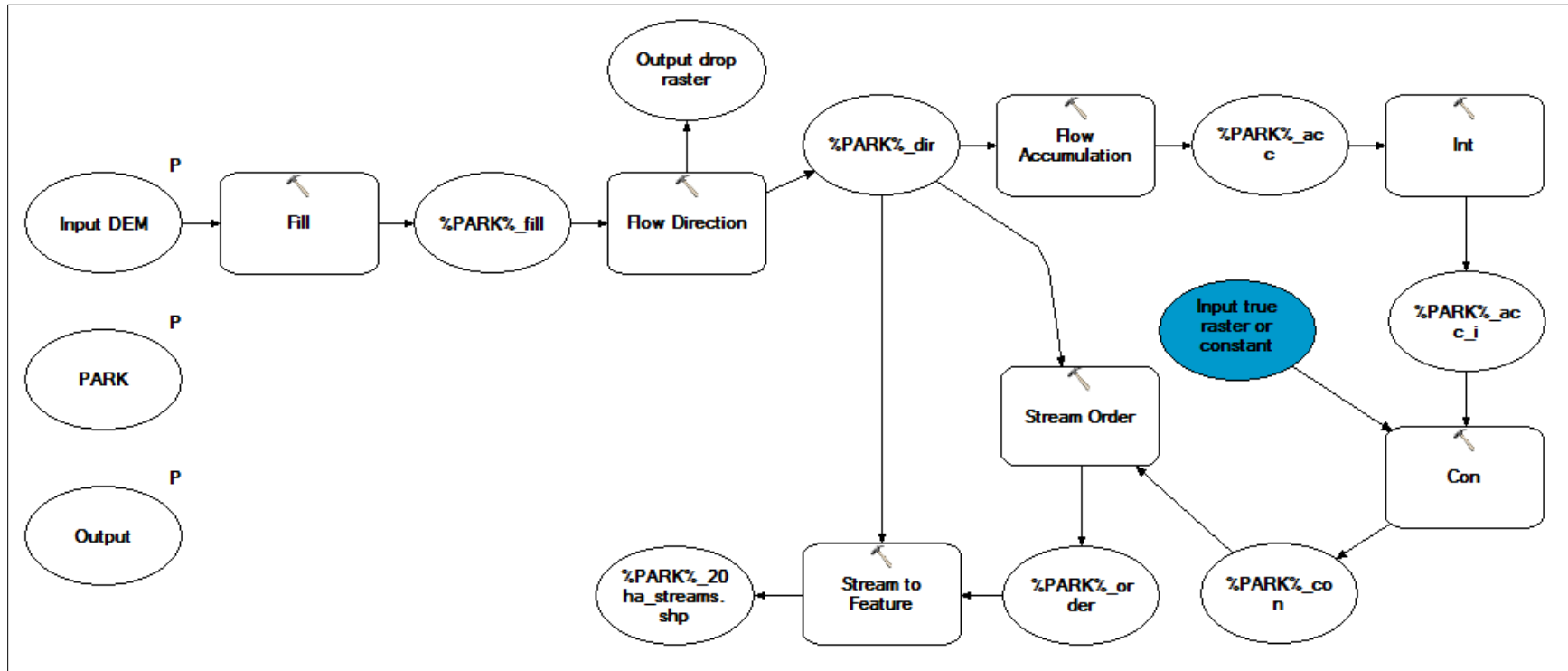


Figure A-1. Model for Watershed Characteristics Tool 1 – Flow Characteristics.

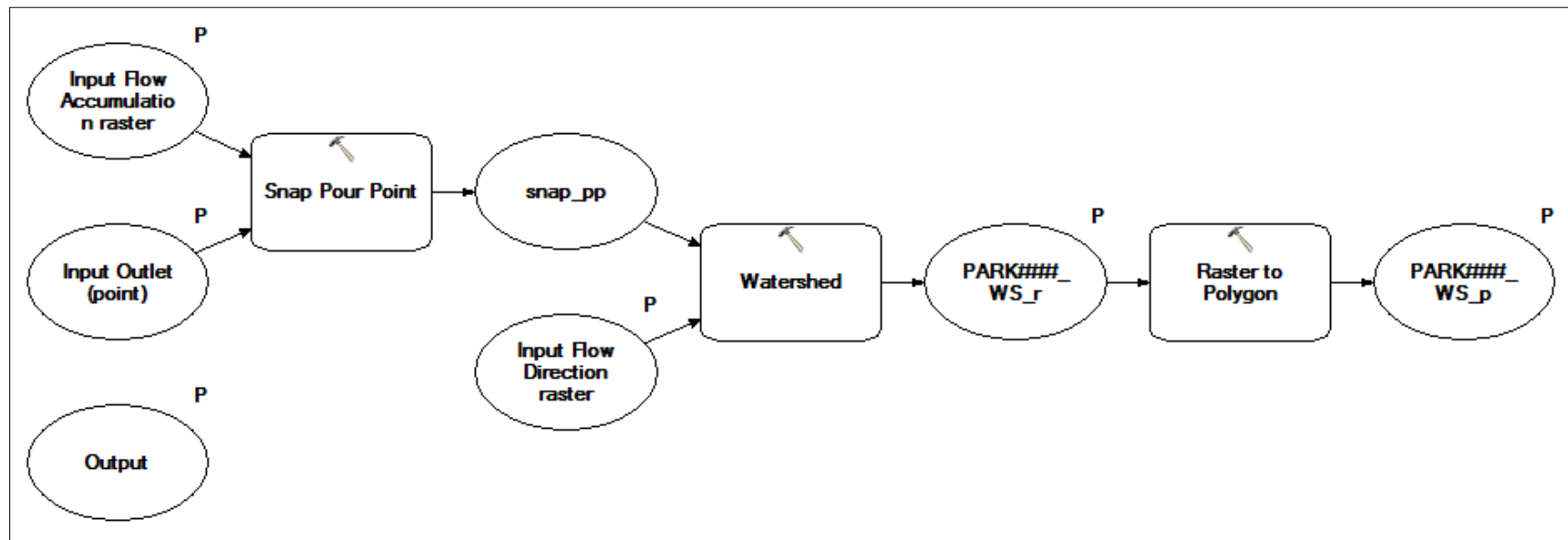


Figure A-2. Model for Watershed Characteristics Tool 2 – Watershed Delineation.

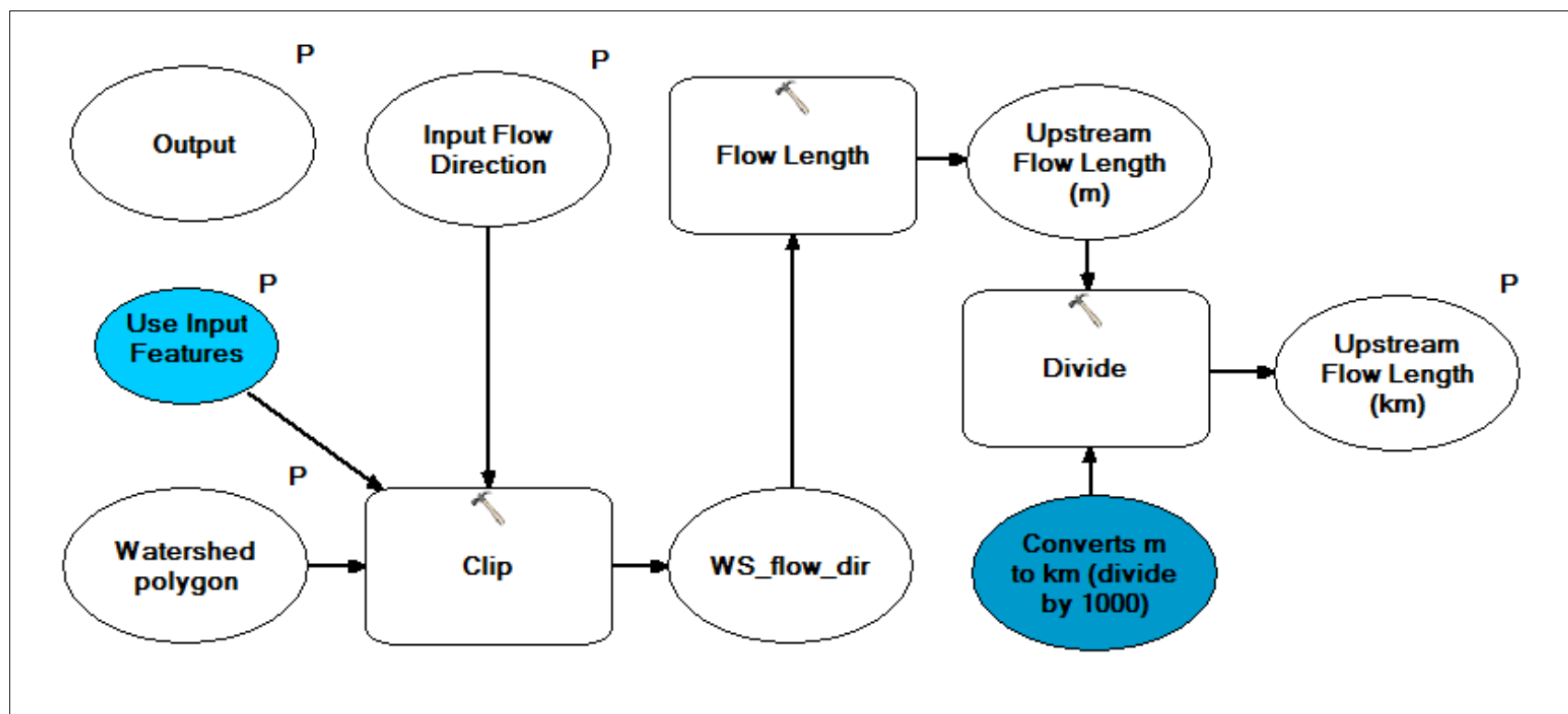


Figure A-3. Model for Watershed Characteristics Tool 3 – Upstream Flow Length.

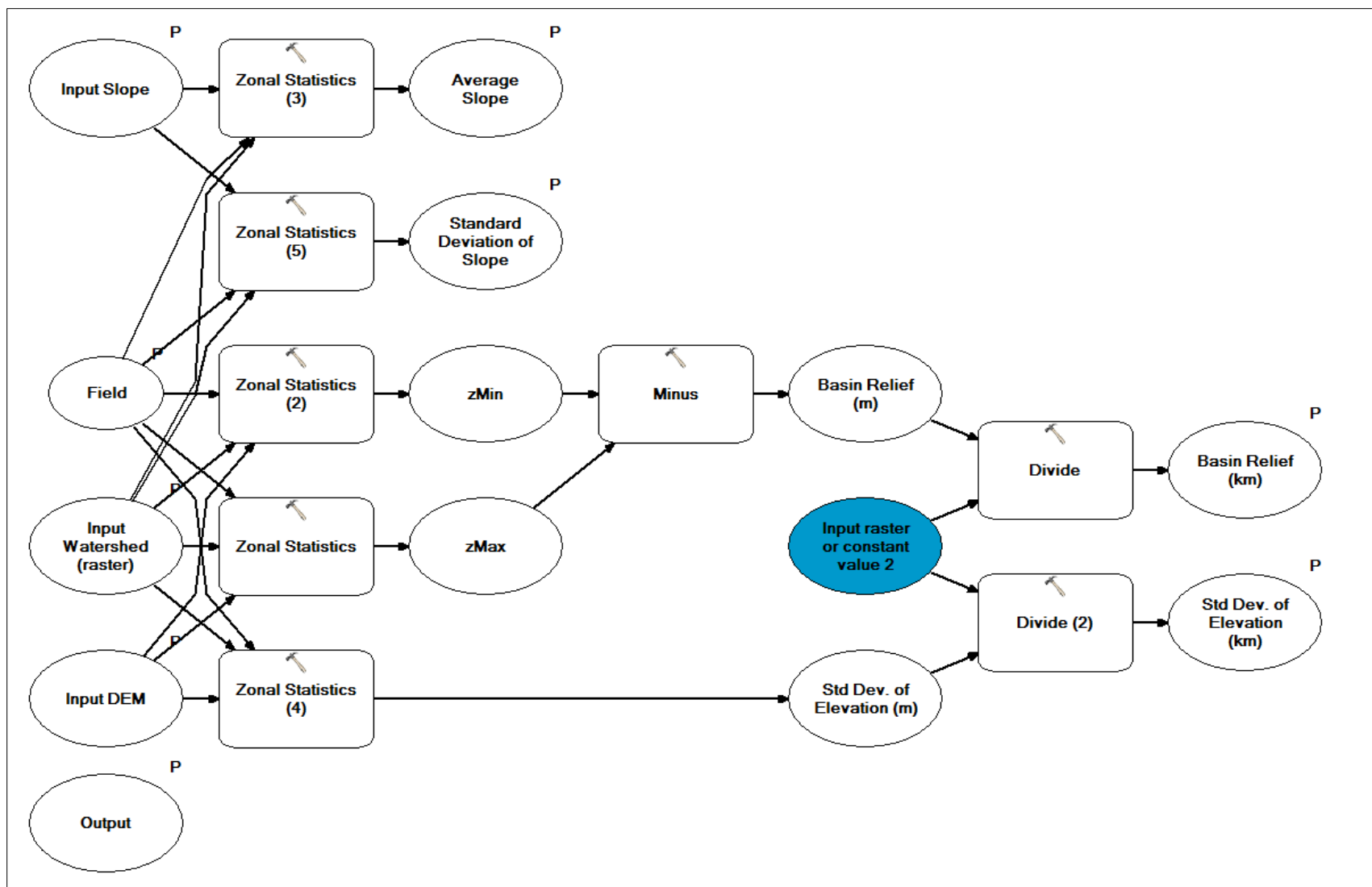


Figure A-4. Model for Watershed Characteristics Tool 4 – Basin Relief and Slope.

Appendix B. R Code to Create Land Use and Land Cover Tables

```
# Change for PARK/SITE
park <- "CHAT"
site.n <- "001"
day <- "20170612"

# Combine site name
site <- paste(park, site.n, sep = "")

# Set working directory
setwd(paste("S:/NEW DIRECTORY
STRUCTURE/Monitoring/StreamHabitat/Wadeable/Data/", park,
"/A_RawData/", site, sep = ""))

# NLCD class values
n.class <- c(11, 12, 21, 22, 23, 24, 31, 41, 42, 43, 52, 71, 81,
82, 90, 95)

# Name of NLCD classes
class.n <- c(
"Open Water",
"Perennial Snow/Ice",
"Dev-Open",
"Dev-Low",
"Dev-Med",
"Dev-High",
"Barren",
"Deciduous",
"Evergreen",
"Mixed Forest",
"Shrub",
"Grassland",
"Pasture",
"Cultivated",
"Woody Wetland",
"Herbaceous Wetland")

# Import the LULC tables
# To add additional years simply copy the lines from a previous
year and add new year
table.2001 <- read.table(paste(site, "_LULC_2001.txt", sep = ""),
header = TRUE, sep = ",")
table.2006 <- read.table(paste(site, "_LULC_2006.txt", sep = ""),
header = TRUE, sep = ",")
table.2011 <- read.table(paste(site, "_LULC_2011.txt", sep = ""),
header = TRUE, sep = ",")
```

```

table.2001[, 'Class'] <- seq(0, nrow(table.2001)-1, 1) # Adds a field
  with correct LULC numbers
table.2006[, 'Class'] <- seq(0, nrow(table.2006)-1, 1)
table.2011[, 'Class'] <- seq(0, nrow(table.2011)-1, 1)

t.2001 <- table.2001[which(table.2001[, 'Class'] %in% n.class), ]
  # Gets rid of additional fields
t.2006 <- table.2006[which(table.2006[, 'Class'] %in% n.class), ]
t.2011 <- table.2011[which(table.2011[, 'Class'] %in% n.class), ]

t.2001[, 'Percent'] <- (t.2001[, 2]/sum(t.2001[, 2]))*100      #
  Calculates percent
t.2006[, 'Percent'] <- (t.2006[, 2]/sum(t.2006[, 2]))*100
t.2011[, 'Percent'] <- (t.2011[, 2]/sum(t.2011[, 2]))*100

# Combine the years and label classes
output <- data.frame(
  Class = class.n,
  "2001" = round(t.2001[, 'Percent'], 3),
  "2006" = round(t.2006[, 'Percent'], 3),
  "2011" = round(t.2011[, 'Percent'], 3))

# Write combined table to csv
write.csv(output, paste(site, "_LULC_", day, ".csv", sep = ""))

```