

# Northern Great Plains Network

National Park Service



## Watershed and Segment Scale Assessment

### *Stream Channel Monitoring*

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### Summary

This standard operating procedure (SOP) outlines the procedures for calculating watershed and segment scale data for NGPN Stream Channel Monitoring (Thornbrugh et al. 2019). The procedures are adapted from Southeast Coast Network Standard Operating Procedure 1.2.15, Wadeable Stream Basin- and Segment-Scale Data Summary—Version 1.0. (McDonald et al. 2018b).

### Revision Log

| Previous Version | Revision Date | Author    | Changes Made                                                   | Reason for Change                                                      | New Version |
|------------------|---------------|-----------|----------------------------------------------------------------|------------------------------------------------------------------------|-------------|
| 2019             | Apr-23        | Y. Wilson | GIS workflow                                                   | Updated to current GIS software                                        |             |
|                  | Apr-23        | A. Rosse  | Redefined watershed parameters                                 | Clarification of terms                                                 |             |
|                  | Apr-23        | Y. Wilson | Used NHDPlus HR and tools                                      | Incorporated the available integrated DEM and NHD products             |             |
|                  | Mar-24        | A. Rosse  | Removal of “perennial” stream class requirement from workflow. | Limited perennial streams in region, but did remove ephemeral streams. |             |
|                  | Mar-24        | G. Galles | Formatting and inclusion of workflow for ArcPro                | Update to ESRI packages for NPS                                        | 1.1         |

This SOP is adopted with modifications from SECN's SOP 1.2.15, *Wadeable stream basin- and segment-scale data summary—Version 1.0* (McDonald et al. 2018b). The original SOP is available from: <https://irma.nps.gov/DataStore/Reference/Profile/2254012>

## Differences in Methods

- Changed the text to fit NGPN file structure.
- Adopted updated hydrography and elevation datasets.
- Specified NGPN-appropriate analysis datum.
- Adopted watershed as standard term for area of analysis (rather than using both basin and watershed).
- NGPN will use the National Hydrography Dataset Plus High Resolution (NHDPlus HR) for all associated site location to conduct the watershed and segment scale assessment (USGS 2017).
- Eliminated ephemeral streams from analysis.
- Updated to current Esri ArcGIS Pro application.

## Introduction

The following standard operating procedure (SOP) outlines the procedure for calculating watershed and segment scale data for the sample reaches chosen as part of the PIP for Stream Channel Monitoring in the NGPN. The purpose of this SOP is to ensure that watershed and segment scale variables are calculated using the same methods and techniques, which will allow watersheds to be compared 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 adopted from methods described in McDonald et al. (2018b). This SOP assumes the user has at least an intermediate understanding of geographic information systems (GIS) and can use the statistical software R (R Core Team 2018).

## Required Materials

- Desktop or laptop computer running ArcGIS Pro 3.x with Spatial Analyst extension.  
Point feature layer of endpoint of sample (SCM) reaches (shapefile/geodatabase feature layer)

- National Hydrography Dataset Plus High Resolution (NHDPlus HR) drainage network dataset and the accompanying NHDPlus HR rasters<sup>1</sup> and VAA tables
- 10-meter digital elevation model (DEM) of study area<sup>2</sup>
- National Land Cover Database (NLCD) datasets<sup>3</sup>
- R statistical software
- NPS Core Standards reference features for polygons found here:  
N:\Monitoring\Stream\_Channel\GIS\TEMPLATES\Data\_Standards\NPSDataStandards\NPS\_CORE\_20160810.gdb\CORE\_py or on the Intermountain Region (IMR) Geographic Resources Sharepoint site, under Documents
- Data Standards Toolbox.pyt toolbox. Find it here:  
N:\Monitoring\Stream\_Channel\GIS\TOOLBOXES
- Data table to record attribute fields from watershed polygons, found here:  
N:\Monitoring\Stream\_Channel\Protocol\Data Entry  
Templates\Watershed\_Characteristics\_Reporting\_Template\_YYMMDD.xlsx.

## Watershed 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 watershed- and segment-scale characteristics for each study reach from a 10-meter DEM. Many of the watershed and segment scale characteristics described in this SOP are suggested by Fitzpatrick et al. (1998). Additional measures of watershed 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 watershed characteristics that have been shown to influence storm runoff and peak flows (McDonald et al. 2018c).

Watershed land use/land cover (LULC) needs to be updated every nine years, dependent on whether a new coverage is available. These LULC metrics will be calculated and reported to the parks along with the other watershed characteristics to help them understand geomorphic and anthropogenic

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<sup>1</sup> Available through [https://www.nhdplus.com/NHDPlus/NHDPlusV2\\_home.php](https://www.nhdplus.com/NHDPlus/NHDPlusV2_home.php). Rasters are found in zipped 7z format files through the Other Format (7z) link within The National Map Products results. Rasters are not included in geodatabase downloads.

<sup>2</sup> Available for download from the USGS through <https://apps.nationalmap.gov/downloader/#/>

<sup>3</sup> Available through <https://www.mrlc.gov/data>

drivers of stream habitat variability. This SOP describes the methods to determine LULC from the National Land Cover Dataset (NLCD, Homer et al. 2015).

The following parameters should be calculated or extracted for each stream channel sampling point and entered into the Watershed\_Characteristics\_Reporting\_Template:

**Watershed Drainage Area (WDA\_sqkm):** refers to the area within which precipitation, sediment, and dissolved constituents are funneled to a common outlet point (Dunne and Leopold 1978).

**Total Stream Length (TSL km):** is the length of all streams that flow to a common outlet.

**Drainage density (DD):** is the ratio of total stream length to drainage watershed area.

**Watershed length (WL km):** the distance as-the-crow-flies from the pour point to the drainage divide, uphill of the upper reach of the main path stream.

**Watershed shape (Wshape):** is calculated by dividing watershed area by watershed length squared. Be careful to use consistent units.

**Slope:** will be characterized by determining the average (**aSlope**), standard deviation (**sdSlope**), and coefficient of variation of slope (**cvSlope**) within the watershed.

**Watershed Relief (WR km):** is the maximum amount of relief (maximum elevation minus minimum elevation) found within the watershed.

**Standard Deviation of Elevation (sdZ km):** is the standard deviation of elevation within the watershed.

**Watershed Relief Ratio (WRR):** is calculated by dividing watershed relief by watershed length. Be careful to use consistent units.

**Entire Stream Gradient (ESG):** 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.  
F

**Stream order (Strahler):** classifies streams based on the number and character of their tributaries (Strahler 1957). NHDPlus HR provides a modified Strahler stream order in the Value-Added Attribute table included in the geodatabase.

**Bifurcation ratio (BiR):** is the ratio of the number of streams in a given Strahler order to the number of streams in the stream order above it (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.

**Segment Gradient (SG):** 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.

**Land Use/Land Cover (LULC):** will be calculated from the most recent NLCD dataset. This dataset classifies land cover using a modification of Anderson et al. (1976).

## Procedure

The following procedures outline how to calculate the watershed characteristics listed above using ArcGIS Pro 3.x. Words in *italics* refer to ArcGIS Pro tools. If you cannot find the tools in ArcGIS Pro from the Geoprocessing Pane (Analysis tab >Geoprocessing section >Tools icon), use the Command Search window above the ribbon. The procedure is complex. Save your project often.

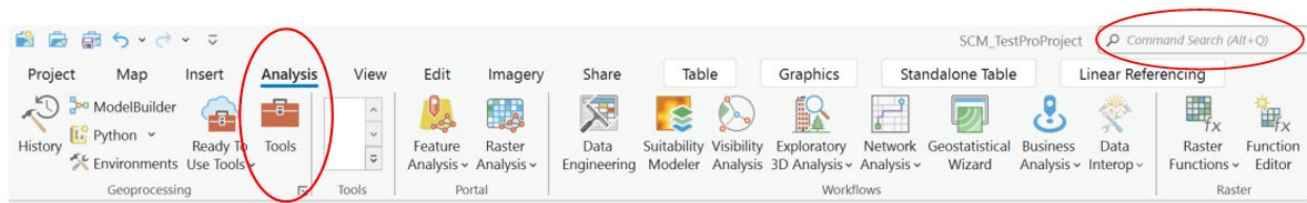


**Figure 1.** Finding the Geoprocessing Pane (Tools)

The procedures outlined in this SOP use a 10-meter DEM. Using a DEM with different resolution will provide a different value for many if not all 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, feature layers will have already been derived. Check (N:\Monitoring\Stream\_Channel\GIS or N:\Monitoring\Stream\_Channel\PARK\GIS) for final products or N:\Monitoring\Stream\_Channel\GIS\NGPN\_SCM\_Watershed\_Delineation\_Data\_and\_Docs\_2023 for reference files prior to running any of the following tools.

## Watershed Characteristics

### A. DATA PREPARATION

1. Before starting this analysis, obtain a 10-meter DEM of the site(s), and the NHDPlus HR geodatabase(s) and rasters for the area(s) of interest. Find the data on the websites listed in footnotes above. Data should also be at N:\Monitoring\Stream\_Channel\GIS\NGPN\_SCM\_Watershed\_Delineation\_Data\_and\_Docs\_2023\NGPN\_SCM\_Import\_Data\_2023\_Reference\_Files has reference DEMs, NHDPlusHR gdb and rasters, NLCD dataset, and NPS boundaries.

2. Save all original data (zipped files are fine) in the Import folder. Do not alter or use this original data.
3. Make a copy (or simply extract the zipped file) to place into the folder  
N:\Monitoring\Stream\_Channel\PARK\GIS\
4. It is possible that your watershed area will cover multiple DEM image tiles. Multiple image tiles must be joined into one image using the *Mosaic* tool.
5. To join the DEMs, use the *Mosaic* tool. This will join all the DEM tiles under the name of the first tile. After using the Mosaic tool, rename your newly combined raster appropriately within the catalog pane, not the contents pane, which will only change the layer's display name. (PARK\_SCM\_DEM\_mosaic\_ra)
6. For NHDPlus HR files, the hydrologic unit (HU) number for the data which you downloaded will be part of the folder name. You will need these tif image files from the raster folder HRNHDPlusRaster[**HU#**]:  
“fdr.tif” (flow direction),  
“fac.tif” (flow accumulation), and possibly  
“hydrodem.tif.” the stream network raster.
7. If you have downloaded a very large area, perhaps HUC4 level data, use *Clip Raster* to clip the rasters to the extent of the DEM data before trying to reproject these very large rasters. Larger rasters take much more time to process.
8. To use the *Clip Raster tool*,
  - a. Input Raster =>  
...Data\Raster\NHDPLUS\_H\_[HU#]\_HUC[#level]\_RASTER\HRNHDPlusRasters[  
HU#]\fdr.tif
  - b. Output Extent => ...Raster\PARK\_SCM\_DEM\_ra
  - c. Rectangle => will autofill once you choose an output extent
  - d. Output Raster Dataset => ...Raster\PARK\_SCM\_NHDfdr\_clip1\_ra.

\*Note: when you clip a raster to a polygon layer later in this SOP, check the box for Use Input Features for Clipping Geometry: otherwise it will clip your raster to a rectangle tangent to your polygon.

\*\*Note: Verify the DEM is projected to NAD 1983 (2011) Contiguous USA Albers prior to following any of the steps in this SOP. As of Feb 2023, the NHDPlus HR rasters arrive in geographic coordinate system NAD1983 with no projection. If any of the files are not in the correct datum and projection, run *Project Raster* as below.

9. To use the *Project Raster* tool:

- a. Input Raster => ...Raster\PARK1\_PARK2\_SCM\_DEM\_ra (only use 2 park codes if the area can be used in two parks – place the names alphabetically).
  - b. Output Raster Dataset => ...Raster\PARK1\_PARK2\_SCM\_DEM\_proj\_ra
  - c. Output Coordinate System => NAD 1983 (2011) Contiguous USA Albers.
10. If need be, repeat the *Project Raster* process for the flow direction “fdr”, the flow accumulation “fac,” and the layer of your pour point, if it is a raster. Output files should be named
  - ...Raster\PARK\_SCM\_NHDfdr\_clip1\_proj\_ra, (assuming raster was clipped)
  - ...Raster\PARK\_SCM\_NHDFac\_clip1\_proj\_ra, (assuming raster was clipped), and
  - ...Raster\PARK\_SCM\_PourPoint\_proj\_ra.
11. Similarly, if it is not in NAD 1983 (2011) Contiguous USA Albers projection, reproject your point feature layer of your pour point to this projection using the *Project* tool.
12. To use the *Project* tool:
  - a. Input Feature Class =>
    - ...Data\Working\PARK\_SCM\_yyyy.gdb\PARK\_SCM\_PourPoint\_pt
  - b. Output Feature Class =>
    - ...Data\Working\PARK\_SCM\_yyyy.gdb\PARK\_SCM\_PourPoint\_proj\_pt
  - c. Output Coordinate System => NAD 1983 (2011) Contiguous USA Albers

\*Note: NHD Flowlines have complex topologic rules which can tend to crash the program if you attempt reprojection when working with so many flowlines. Later in this process we will select fewer, then clip and reproject flowlines.

## B. DEFINE THE WATERSHED

13. Align the pour point where the water will flow on the NHD rasters (N:\Monitoring\Stream\_Channel\GIS or N:\Monitoring\Stream\_Channel\PARK\GIS), The *Snap Pour Point* tool creates a one-cell raster of your pour point, moved slightly or snapped to a nearby high value cell in a flow accumulation raster. If the pour point is already a raster, it will simply create a new raster moved to the highest local flow accumulation cell.
14. To use the *Snap Pour Point* tool:
  - a. Input Accumulation Raster => (...Raster\PARK\_SCM\_NHDFac\_clip1\_proj\_ra)
  - b. At first, leave Snap Distance blank. If you get no output, you will need to enter a snap distance (in number of raster cells) and try again.
  - c. Open the NHDPlus HR raster “hydrodem” so you can see how far the points should be snapped. Zoom in closely to your pourpoint and count how many cells over it should move. This number should work as your snap distance.

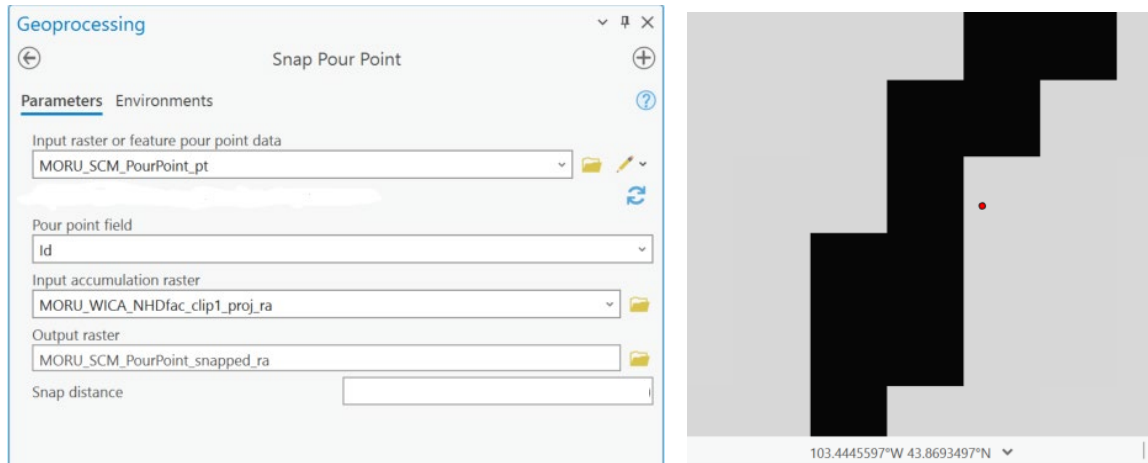


**Figure 2.** On the right, the red pour point needs to be snapped only 1 cell over. Change the snap distance to 1.

15. To use the *Watershed* tool:

- Input D8 flow direction raster => reprojected and clipped Flow Direction PARK\_NHDfdr\_clip1\_proj\_ra raster.
- Use the PARK\_SCM\_PourPoint\_snapped\_ra raster for the feature pour point.
- Name the output raster and run the tool.

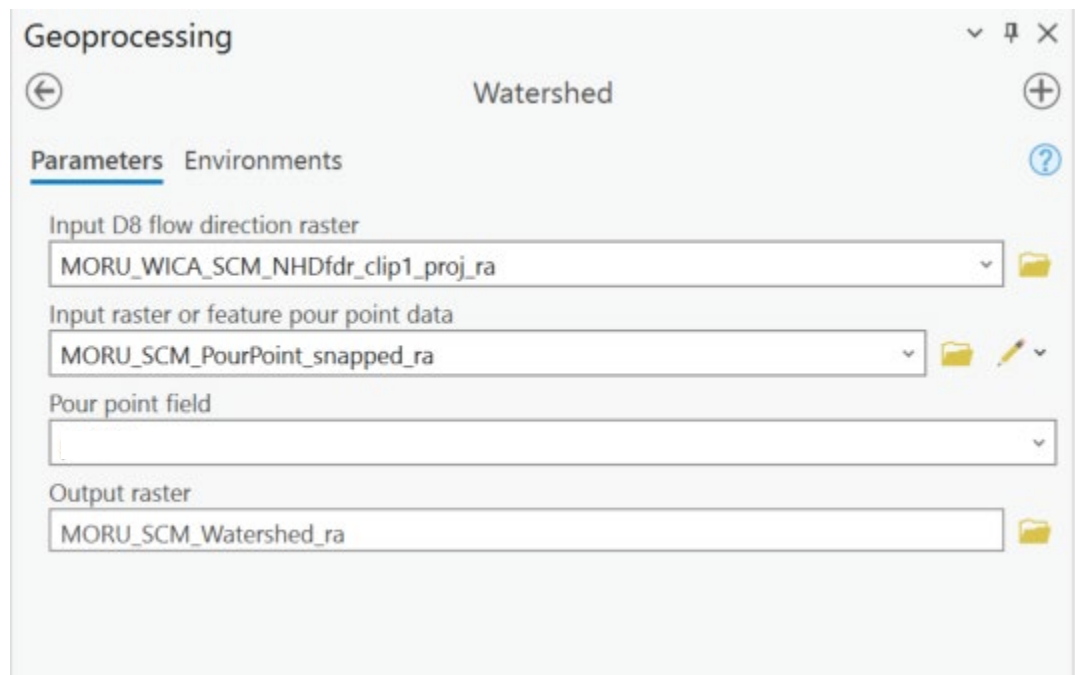


**Figure 3.** The Geoprocessing pane displaying the watershed tool, inputs, and suggested output.

16. The output should approximate either the NHDPlus HR geodatabase's WBD HUC12 boundaries or the NHDPlus Feature Dataset Catchment feature polygons (if your watershed is

smaller than a single HUC-12 area). Your watershed will likely vary from these polygons most as you near your pour point.

17. Convert the watershed to a polygon –

- a. Run the *Raster to Polygon* tool on the PARK\_SCM\_Watershed\_proj\_ra raster. The zigzag-edged polygon will likely fit into the NHDPlus HR HUC-12 or Catchment layers nicely. Do not check the Simplify Polygons box.

18. To check that the watershed tool was successful, compare the watershed polygon you just completed to the existing HUC12.

19. A successful watershed should fit the boundaries of the HUC12 and have similar edges. If the completed watershed does not match closely with the existing HUC or the edges are poorly defined, continue with the steps below, assuming the watershed tool failed.

20. If available, compare the completed watershed with StreamStats, a USGS based [online tool](#).

- a. Nebraska and Wyoming are still being completed in StreamStats, meaning parks in these states will not be able to be checked by this method
- b. By selecting an area near the pour point on StreamStats, you can get a rough idea of the watershed basin and associated watershed delineation characteristics like watershed area and mean annual flow. Those parameters produced, Stream Stats Area, Mean Annual Flow, 2 year flood, 50 year flood and 100 year flood) should be recorded on the Watershed\_Characteristics\_Reporting\_Form.

21. Sometimes the watershed tool fails by having no watershed output at all. If this is the case, continue with the steps below to create the watershed.

For WICA and MORU and perhaps other parks, watershed delineation should be done. You will still need to run the *Trace* tool workflow below even if you have an acceptable watershed. Stop once you have a PARK\_SCM\_NHDFlowline\_Trace\_In layer. Then skip down to the section for the Total Upstream Stream Length (TSL) calculation.

### C. TRACE METHOD

Sometimes the *Watershed* tool fails. When this happens, you will need to use the *Trace* tool.

22. *Trace* is a tool which selects all connecting flowlines. In the Upstream mode, it captures most upstream flowlines. It did not capture streams which disappear in sinks or ponds. However, these still contribute to the watershed. *Trace* requires a trace network.
23. The NHDPlus Hydrography feature dataset includes HYDRO\_NET, a geographic network of the other Hydrography feature layers.
24. Use the *Convert Geometric Network to Trace Network* tool on HYDRO\_NET.
25. To use the *Convert Geometric Network to Trace Network* tool:
  - a. Input Geometric Network=>  
NHDPLUS\_H\_[HU#]\_HUC[#level]\_GDB\Hydrography\HYDRO\_NET
  - b. Output Trace Network Name=> NGPN\_[HU#]\_HYDRO\_Tracenet\_net
  - c. This tool alters the network within the NHDPlus geodatabase.
26. Run *Enable Network Topology* (in Trace Network Tools):
  - a. Input Trace Network=>  
NHDPLUS\_H\_[HU#]\_HUC[#level]\_GDB\Hydrography\NGPN\_[HU#]\_HYDRO\_Tracenet\_net
27. Run *Trace* tool:
  - a. Input Trace Network=>  
NHDPLUS\_H\_[HU#]\_HUC[#level]\_GDB\Hydrography\NGPN\_HYDRO\_Tracenet\_net
  - b. Trace Type=> Upstream
  - c. Starting Points=> PARK\_SCM\_PourPoint\_snapped\_ra
  - d. Barriers=> (leave blank)
  - e. Do not check boxes for: include barrier features, validate consistency, ignore barriers at starting points, or allow indeterminate flow
28. Trace will **select** NHDFlowlines which include and are upstream of the pour point.
29. Right click on the NHDFlowline layer.
30. Choose Data>Export Features.
31. Navigate to your PARK\_SCM\_yyyy.gdb, and name the layer  
PARK\_SCM\_NHDFlowline\_Trace\_ln.
  - a. \*Note: this particular layer remains in NAD83 coordinate system because the HYDRO\_NET was in NAD83. It will also include the downstream end of the flowline below the pour point, which we will need to clip.

This traced flowline layer PARK\_SCM\_NHDFlowline\_Trace\_In will estimate the full upstream extent of the watershed. We will choose NHD data to outline the upstream end.

32. From within ...Data\Working\NHDPLUS\_H\_[HU#]\_H[#level]\_GDB, add both NHDPlus\NHDPlusCatchment and WBD\WBDHUC12 to your map.
33. If your flowlines all fall within one WBDHUC12 polygon, you can ignore the WBDHUC12 layer.
34. Use *Select By Location* to find all the catchments (or multiple HU-12 polygons) which intersect PARK\_SCM\_NHDFlowline\_Trace\_In. You may get one additional polygon at the downstream end of the flowline.

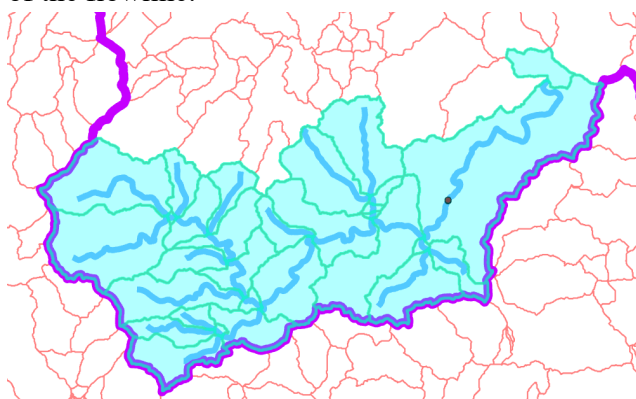


**Figure 4.** Blue traced flowlines are used to select red outlined catchment polygons within one purple HUC-12 polygon. Note the extra selected polygon touching the end of the flowline.

35. Use Ctrl+Click to unselect the extraneous polygon, or unselect it from the attribute table.
36. Right click the NHDPlusCatchments (or WBDHUC12 polygons) layer in the Table of Contents. Choose Data>Export Data.
37. Name the new layer PARK\_SCM\_CatchmentSelect\_py or PARK\_SCM\_HUC12Select\_py.
38. Project the catchments or HUC-12 polygons to NAD1983(2011) Contiguous USA Albers.
39. Run the *Project* tool:
  - a. Input Feature Class => ...Data\Working\PARK\_SCM\_YYYY.gdb\PARK\_SCM\_CatchmentSelect\_py or ... PARK\_SCM\_HUC12Select\_py
  - b. Output Feature Class => ...Data\Working\PARK\_SCM\_YYYY.gdb\PARK\_SCM\_CatchmentSelect\_proj\_py or Data\Working\PARK\_SCM\_YYYY.gdb\PARK\_SCM\_HUC12Select\_proj\_py
  - c. Output Coordinate System => NAD 1983 (2011) Contiguous USA Albers

We have now defined the area of the upstream end of the watershed. All that remains to be clipped is the area near the pour point. If you previously obtained an acceptable watershed result near the pour

point – usually no matter what the upstream end looked like – you can use that to define the pour point end of the final watershed. Select only the single polygon which contains the pour point within PARK\_SCM\_CatchmentSelect\_proj\_py or PARK\_SCM\_HUC12Select\_proj\_py.

40. Use *Clip* to trim off the selected polygon below the pour point, creating a new layer.

41. Run the *Clip* tool:

- a. Input Features or Dataset => PARK\_SCM\_CatchmentSelect\_proj\_ or PARK\_SCM\_HUC12Select\_proj\_py with one polygon selected which contains the pour point
- b. Clip Feature => PARK\_SCM\_Watershed\_failed\_proj\_ra (can be raster or polygon)
- c. Output Features or Dataset => PARK\_SCM\_Catchment\_proj\_clipped\_py or PARK\_SCM\_HUC12Select\_proj\_clipped\_py

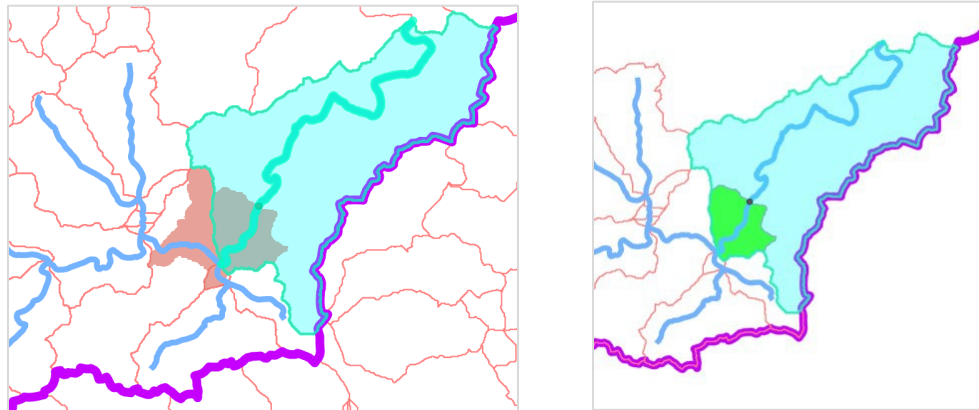


**Figure 5.** Left: selected catchment to be clipped at pourpoint by the red failed watershed polygon which was created from regular DEM and flow direction rasters. Right: new green clipped catchment ends at pourpoint.

You may need to do some minor manual editing of vertices if there are extra slivers outside the new polygon or if your failed watershed outline did not extend to the catchment boundary in areas which will be inside the final watersheded polygon.

42. Use Edit tab>Modify>Edit Vertices and choose your layer to be edited.
43. Turn on snapping (point to point style) on the top ribbon.
44. Save your edits using the Save icon on the Edit tab, then save your project.

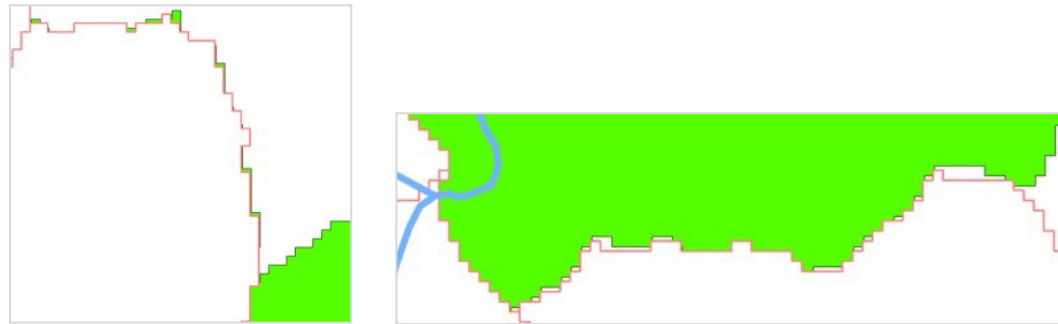


**Figure 6.** Left: extra slivers may be created, which can be deleted with manual editing. Right: the failed watershed ended short of the edge of the catchment polygon, so the newly edited polygon ended short too. Move these vertices to snap to the catchment polygon outline where they are already very close. In that way the new watershed outline will not create an unintended indentation.

45. *Append* this clipped polygon to your CatchmentSelect proj\_py or PARK\_SCM\_HUC12Select\_proj\_py
46. Use the attribute table to delete the single line in the attribute table of the original catchment polygon from the layer.
47. *Dissolve* the polygons into one output PARK\_SCM\_Watershed\_fromTrace\_py. Check the box for Create multipart features.
48. Run the *Append* tool:
  - a. Input Dataset => PARK\_SCM\_Catchment\_clipped\_py
  - b. Target Dataset => PARK\_SCM\_CatchmentSelect proj\_py
  - c. Field Matching Type => Input fields must match target fields
49. Select the old polygon extending past the pour point. Delete only that single polygon.
50. Run the *Dissolve* tool:
  - a. Input Features => PARK\_SCM\_CatchmentSelect proj\_py or PARK\_SCM\_HUC12Select\_proj\_py
  - b. Output Feature class => PARK\_SCM\_Watershed\_fromTrace\_proj\_py
  - c. Keep Create multipart features checked.

#### **D. PREPARE WATERSHED POLYGON**

51. Add NPS Core Standards attribute fields to your watershed polygon.
52. Run the **Data Standards Toolbox.pyt** tool called *Add Fields and Assign Domains* on your final watershed polygon. Find the tool here:  
N:\Monitoring\Stream\_Channel\GIS\TOOLBOXES. The tool requires a reference layer.
53. Use the Core Standards polygon as that reference from here:  
N:\Monitoring\Stream\_Channel\GIS\TEMPLATES\Data\_Standards\NPSDataStandards\NPS\_CORE\_20160810.gdb\CORE\_py, or download it from the Intermountain Region (IMR) Geographic Resources Sharepoint site, under Documents.
54. Add watershed characteristics measurement fields to your watershed polygon. Watershed Characteristic fields are on the Watershed\_Characteristics\_Reporting\_Form and on [page 4](#) of this document.
55. Run the *Add Fields (multiple)* tool on your watershed polygon.
56. NGPN SCM's custom Template Table is found here:  
N:\Monitoring\Stream\_Channel\GIS\TEMPLATES\NGPN\_SCM\_WatershedFieldsForPolygons.csv.
  - a. As new National Land Cover Datasets become available, new fields will need to be added to the NGPN\_SCM\_WatershedFieldsForPolygons.csv table. As of the time of writing in 2023, NLCD's most recent dataset is 2019.
57. Add the Watershed Area
58. If you have not added the multiple polygon attribute fields to your watershed polygon layer, add this attribute field first
59. Right click your watershed polygon, and open the attribute table.
60. At the top of the table is a button "Add" to add an attribute field. Add a new field with the heading WDA\_sqkm.
  - a. The Alias repeats the name. Data Type is Float. Number Format is Numeric. Leave other defaults as is.
61. Save your edits via the large SAVE icon in the top middle of the screen (Edit tab must be open). Close the Fields table.
62. Right click at the top of the WDA\_sqkm attribute field. Choose Calculate Geometry.
  - a. Property = Area(geodesic). Area unit = square kilometers. Coordinate system = NAD\_1983\_2011\_Contiguous\_USA\_Albers.

## G. TOTAL UPSTREAM STREAM LENGTH (TSL\_km)

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, NHD Flowlines will be used to calculate the TSL for each drainage watershed. The *Clip (Analysis Tools)* tool will be used to isolate the stream network for each reach's watershed.

63. If you have not already done so, run the Trace Method workflow on the HYDRO\_NET file as described above in Section C.

64. If your watershed is small and you can see that the *Trace* process selected all the NHD Flowlines in the watershed, you can simply *Project* PARK\_SCM\_NHDFlowline\_Trace\_In, then clip the traced projected flowlines to the polygon of the watershed.

a. *Project* tool:

- i. Input Feature Class => PARK\_SCM\_NHDFlowline\_Trace\_In
- ii. Output Feature Class => PARK\_SCM\_NHDFlowline\_Trace\_proj\_In
- iii. Output Coordinate System => NAD 1983 (2011) Contiguous USA Albers
- iv. Do NOT check the box for Preserve Shape.

65. If *Trace* did not capture all the flowlines in the watershed (disappearing streams will not be captured), you can create a subset of the NHD Flowlines by clipping to the CatchmentsSelect or HUC12Select layer. Then reproject to NAD1983(2011) Contiguous USA Albers projection, and then clip them to the watershed polygon.

a. *Clip* tool

- i. Input Features => PARK\_SCM\_NHDFlowlines
- ii. Clip Features => PARK\_SCM\_CatchmentSelect\_proj\_py OR PARK\_SCM\_HUC12Select\_proj\_py
- iii. Output Feature Class => PARK\_SCM\_Flowlines\_clpCatchment\_In OR PARK\_SCM\_Flowlines\_clpHUC12\_In

b. *Project* tool:

- i. Input Features => PARK\_SCM\_Flowlines\_clpCatchment\_In OR PARK\_SCM\_Flowlines\_clpHUC12\_In
- ii. Output Feature Class => PARK\_SCM\_Flowlines\_clpCatchment\_proj\_In OR PARK\_SCM\_Flowlines\_clpHUC12\_proj\_In
- iii. Output Coordinate System=> NAD1983(2011) Contiguous USA Albers

- c. *Clip* tool:
    - i. Input Features => PARK\_SCM\_Flowlines\_clpCatchment\_proj\_ln OR PARK\_SCM\_Flowlines\_clpHUC12\_proj\_ln
    - ii. Clip Feature => PARK\_SCM\_Watershed\_from[YourMethod]\_proj\_py
    - iii. Output Feature Class => PARK\_SCM\_Flowlines\_proj\_clpWS\_ln
66. For some parks, the stream network may include ephemeral streams. To remove these, first create a selection.
67. Make a copy of your flowlines first to preserve this data.
- a. You will use the *Select by Attribute* tool
    - i. Input Features => PARK\_SCM\_Flowlines\_proj\_clpWS\_ln
    - ii. Expression => FCode = 46007
  - b. With this selection, turn editing on in your attribute table.
  - c. From here, you can delete you selection, removing all ephemeral streams.
  - d. To save, turn editing off and accept changes
68. 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).
69. Right-click the “CalcLength\_km” field and use the Calculate Geometry (property= Length, geodesic;
- a. Length Unit = kilometers
  - b. Coordinate system = Your State Plane coordinate system
  - c. Option to calculate the length of each segment in kilometers.
70. Now that the streams have been attributed with their lengths (in kilometers), right-click the heading of the CalcLength\_km attribute field.
71. Choose Summary Statistics to create a table in the geodatabase with the SUM of the field.
72. Open the table (it may be at the bottom of your map), and copy the SUM value into the attribute table of your watershed polygon.
73. Add a field named “TSL\_km” to the watershed polygon

74. Populate this field with the sum of the “CalcLength\_km” field from the clipped flowline feature class.

## **H. Drainage Density (DD)**

75. 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 “WDA\_km.”

## **I. Watershed Length (WL\_km)**

Find the lowest elevation in this immediate area. This differs from the former SOP which used a measure which followed the sinuous main stream path to the upper watershed divide. The NHDPlus HR Value Added Attribute (VAA) Table includes an attribute Stream Level for each flowline. **The lowest level in any area will be the main stem or main path of the stream.** If the main path stream does not drain a significant path of the watershed (including when or if using “main path” from NHDPlus HR attribute tables) -- for example, above Wind Cave SCM 001 (2022) -- use a major stream which best represents the full length of the watershed. (NHDPlus HR 2023).

76. Right Click at the top of the Stream Level attribute field. Choose Sort Ascending.
77. Select all the rows with the lowest integer Stream Level. This should highlight the main path in the watershed.
78. Right Click on the layer in the table of contents. Choose Selection>Make layer from selected features. A new layer will appear in the Table of Contents.
79. Right click on the new layer which ends in “selection.” Choose Data>Export Features. Call this new layer PARK\_SCM\_Flowline\_MainPath\_ln.

## **J. Watershed Shape (WShape)**

80. Once WL has been calculated, add a field to the PARK###\_WS.shp called WShape, and use the field calculator to divide DA by  $WL^2$  and calculate WShape.

## **K. Watershed Relief (WR), Watershed Relief Ratio (WRR) and Slope (aSlope, sdSlope, cvSlope)**

Watershed relief (WR), 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 - *Watershed Relief and Slope*).

81. Using the Watershed Relief and Slope tool
- The inputs that are needed to run this tool are the Output (site) folder
  - an input watershed raster
  - an input DEM (not hydro-corrected)

- d. an input Slope raster (use the *Slope* tool if one hasn't already been created).

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 C-4).

- 82. Use the *zonal statistics* tool to calculate aSlope and sdSlope.
- 83. Once the tool has been run, add fields for each of the variables that were just calculated (aSlope, sdSlope, BR\_km, sdZ\_km).
- 84. Make each of the fields DOUBLE and populate them with the value of each exported raster.
- 85. Using the zonal statistics calculated above, also calculate the coefficient of variance of the slope (cvSlope)
  - a. To do this: create a new attribute field.
  - b. In the field calculator:  $\text{sdSlope/aSlope} * 100$
  - c. This will calculate cvSlope for all values.
- 86. After all the above variables have been attributed to the PARK###\_WS.shp, add a field (DOUBLE) named "BRR" and calculate the watershed relief ratio by dividing watershed relief (BR) by watershed length (BL).

#### **L. 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 NHD Plus HR Value Added Attribute (VAA) Table includes an attribute Stream Level for each flowline. The lowest level in any area will be the main stem or main path of the stream. Using ArcGIS Pro,

- 87. The first step is to create a new shapefile in the N:\Monitoring\Stream Channel\PARK\GIS folder named PARK###\_ESG\_pts.
- 88. Add this shapefile to an ArcMap document along with the Watershed Length raster and the clipped NHDPlus flowlines.
- 89. The next step is to determine the flow length that corresponds to 85% and 10% upstream from the watershed outlet (e.g., if maximum Watershed Length equals 1 km, 85% = 0.85 km and 10% = 0.10 km).
- 90. Manually find the pixels on the flow length raster that are closest to these distances (along the main stem) and place points there.

91. After the points have been placed, determine their elevations from the (un-hydrologically-corrected) DEM.
92. Using these elevations, calculate ESG by dividing the difference in elevations (be sure to convert to kilometers) by the stream length between.
93. Add a field to the PARK###\_WS.shp named ESG (DOUBLE) and attribute this field with the calculated ESG.

#### **N. Segment Gradient (SG)**

A shapefile containing the NHDPlus flowlines, clipped and reprojected, is needed to complete this section. If the stream network has not been created, see the Total Stream Length section above.

94. 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.

#### **O. Stream Order (Strahler)**

A shapefile containing the NHDPlus flowlines and the VAA table found within the geodatabase is needed to complete this section.

95. The NHDPlus flowlines come with stream order already attributed, at stream order 4 and higher. Check to be sure these are in the attribute table.
96. You may visualize these to check they are as expected by adding the flowlines shapefile and changing symbology to variable by stream order. This will assign a different color to each stream order for quick visualization.

#### **P. Bifurcation Ratio (BiR)**

This section will also use the clipped NHD Plus flowlines 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 order above it (e.g., number of first order streams/number of second order streams).

97. To calculate the bifurcation ratio, add together all bifurcation ratios and divide by the maximum stream order minus one.
  - a. If the stream is a first order stream, the use '1' as the BiR.
98. Once the BiR has been calculated, add a field to the PARK###\_WS.shp named "BiR" (Type: DOUBLE) and add this value.

99. Once all of the watershed characteristics have been calculated, export the PARK###\_out feature class attribute table to N:\Monitoring\Stream Channel\ PARK\Data and name it PARK###\_WatershedCharacteristics\_YYYYMMDD.txt (date at end of file should be date that the data were exported).

#### **Q. 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. 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 at the following location: SCM GIS folder (N:\Monitoring\Stream\_Channel\GIS) 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.

100. To use the *Zonal Histogram* tool:

- 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

101. After all the tables are created, export the table as a .csv and save them to N:\Monitoring\Stream\_Channel\ \PARK\Data. Name them PARK###\_LULC\_YYYY.csv.

- a. To do this, right click on the table in the Catalog pane and click export. This will open the *Export Table* tool.
- b. The input table will be automatically added, be sure to name and save the file as shown above and specify that the export is as a .csv table.

102. 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.

## Literature Cited

- Anderson, J. R., E. E. Hardy, J. T. Roach, and R. E. Witmer. 1976. A land use and land cover classification system for use with remote sensor data. Geological Survey Professional Paper 964. United States Department of the Interior, Washington, D.C.
- Dunne, T. and L. B. Leopold. 1978. Water in environmental planning: San Francisco, W. H. Freeman and Co.
- Fitzpatrick, F. A., I. R. Waite, P. J. D'Arconte, M. R. Meador, M. A. Maupin, and M. E. Gurtz. 1998. Revised methods for characterizing stream habitat in the National Water Quality Assessment Program. U.S. Geological Survey Water Resources Investigations Report 98-4052. Available at: <https://pubs.usgs.gov/wri/wri984052/index.html> (last accessed December 2018).
- Homer, C., J. Dewitz, L. Yang, S. Jin, P. Danielson, G. Xian, J. Coulston, N. Herold, J. Wickham and K. Megown. 2015. Completion of the 2011 National Land Cover Database for the conterminous United States—representing a decade of land cover change information. *Photogrammetric Engineering and Remote Sensing*, 81(5):345-354.
- McDonald, J. M., M. B. Gregory, J. W. Riley, and E. N. Starkey. 2018a. Monitoring Wadeable stream habitat conditions in Southeast Coast Network parks: Protocol narrative. Natural Resource Report NPS/SECN/NRR—2018/1715. National Park Service, Fort Collins, Colorado.
- McDonald, J. M., M. B. Gregory, and J. Riley. 2018b. Wadeable stream basin- and segment-scale data summary—Version 1.0. Southeast Coast Network Standard Operating Procedure NPS/SECN/SOP—1.2.15. Southeast Coast Network, Athens, Georgia.
- McDonald, J. M., D. S. Leigh, and C. R. Jackson. 2018c. Watershed- to continental-scale influences on winter stormflow in the Southern Blue Ridge Mountains: *Journal of Hydrology* 563: 643–656. Available at: <https://www.sciencedirect.com/science/article/pii/S0022169418304335> (last accessed August 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).
- R Core Team. 2018. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL <https://www.R-project.org/>.
- Strahler, A. N. 1957. Quantitative analysis of watershed geomorphology. *Transactions, American Geophysical Union* 38:913–920.
- Thornbrugh, D. J., I. W. Ashton, A. R. Jarding, J. S. Mills, and K. Paintner-Green. 2019. Protocol implementation plan for stream channel monitoring in the Northern Great Plains Network:

narrative version 1.0. Natural Resource Report NPS/NGPN/NRR—2019/1918. National Park Service, Fort Collins, Colorado.

U.S. Geological Survey. 2017. National Hydrography Dataset Plus High Resolution (NHDPlus HR) - USGS National Map Downloadable Data Collection.

## Appendix A – Watershed Characteristics Toolbox

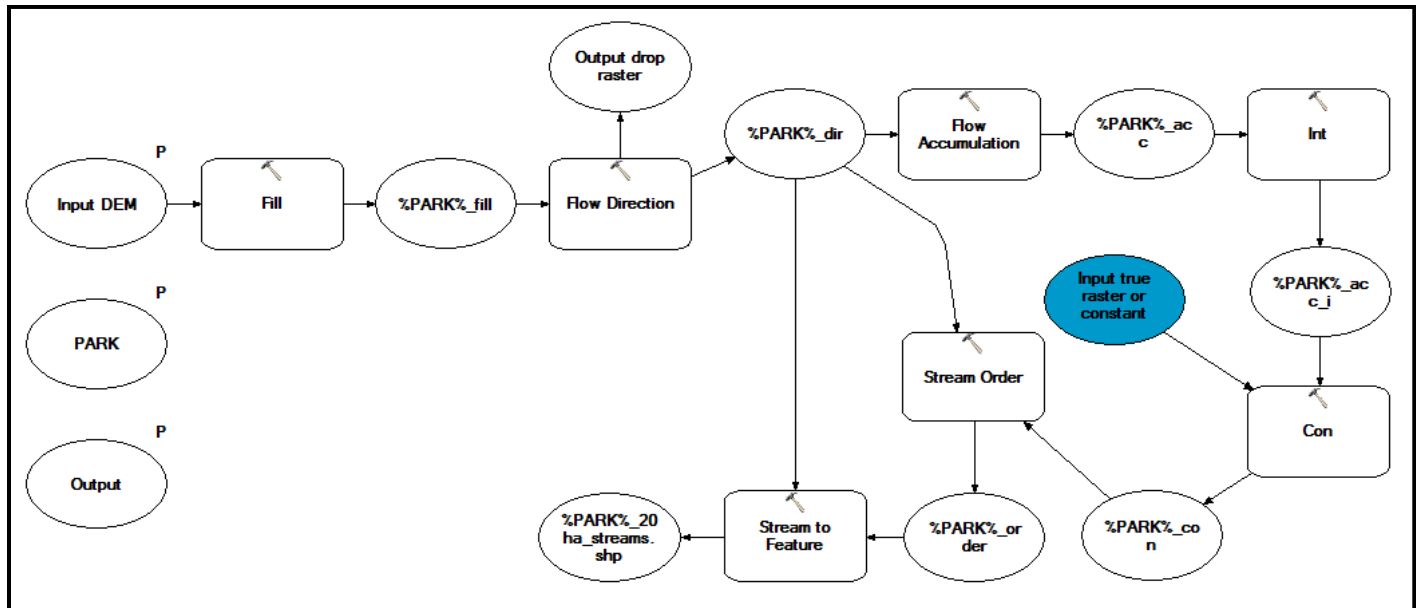


**Figure A-1.** Model for Watershed Characteristics Tool 1 – Flow Characteristics.

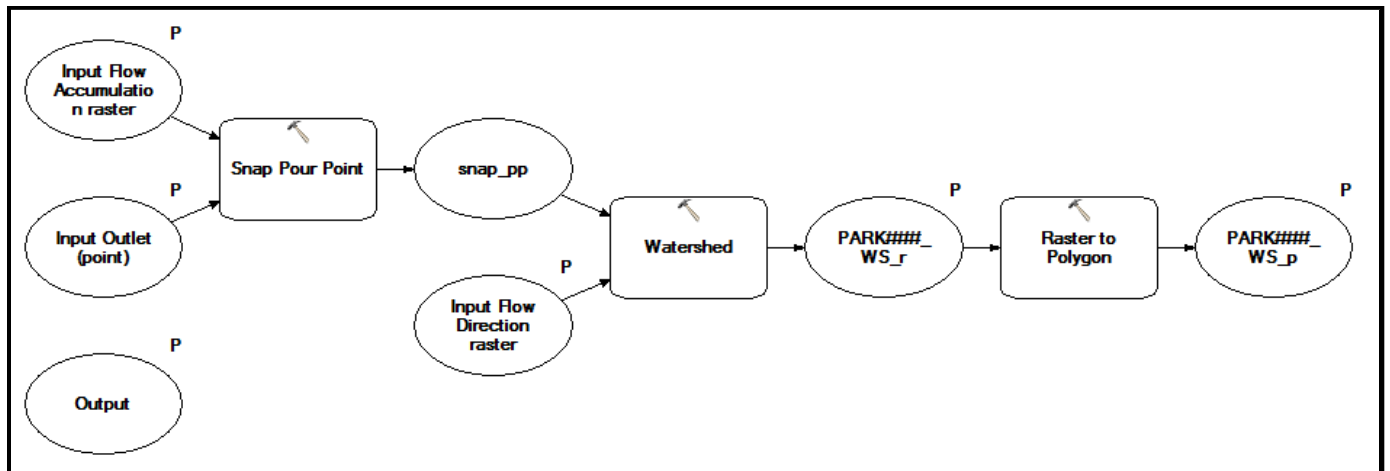


**Figure A-2.** Model for Watershed Characteristics Tool 2 – Watershed Delineation.

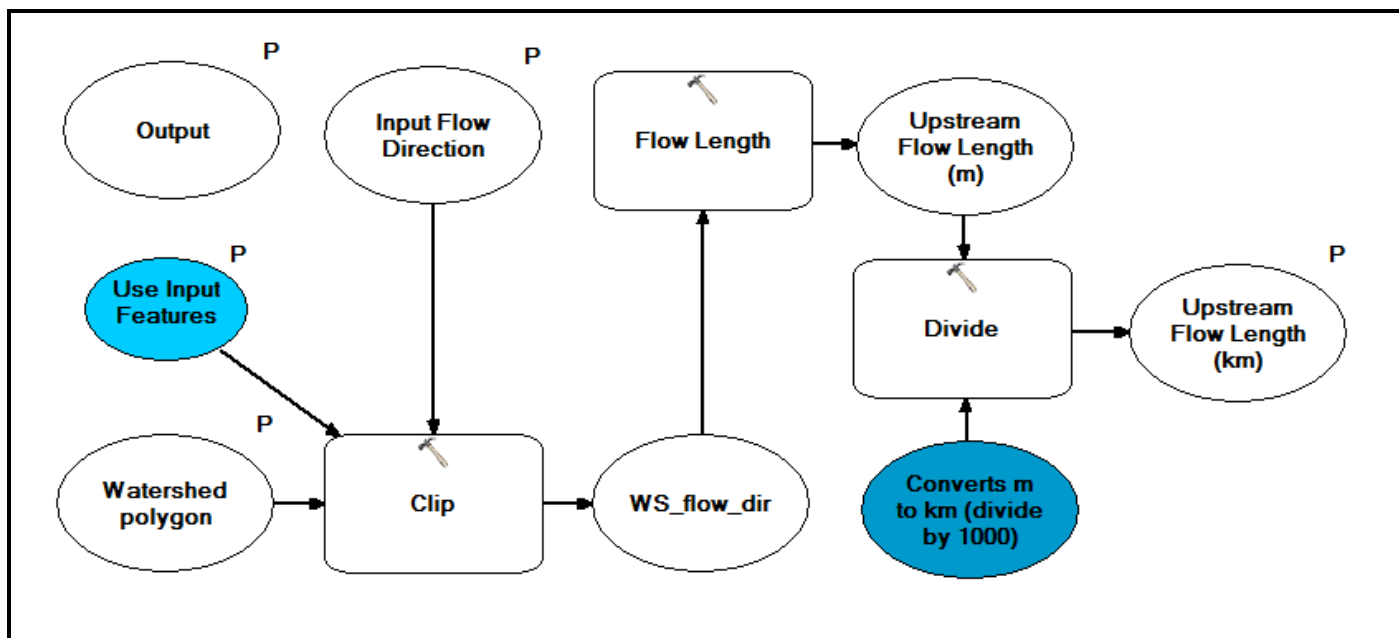


**Figure A-3.** Model for Watershed Characteristics Tool 3 – Upstream Flow Length.

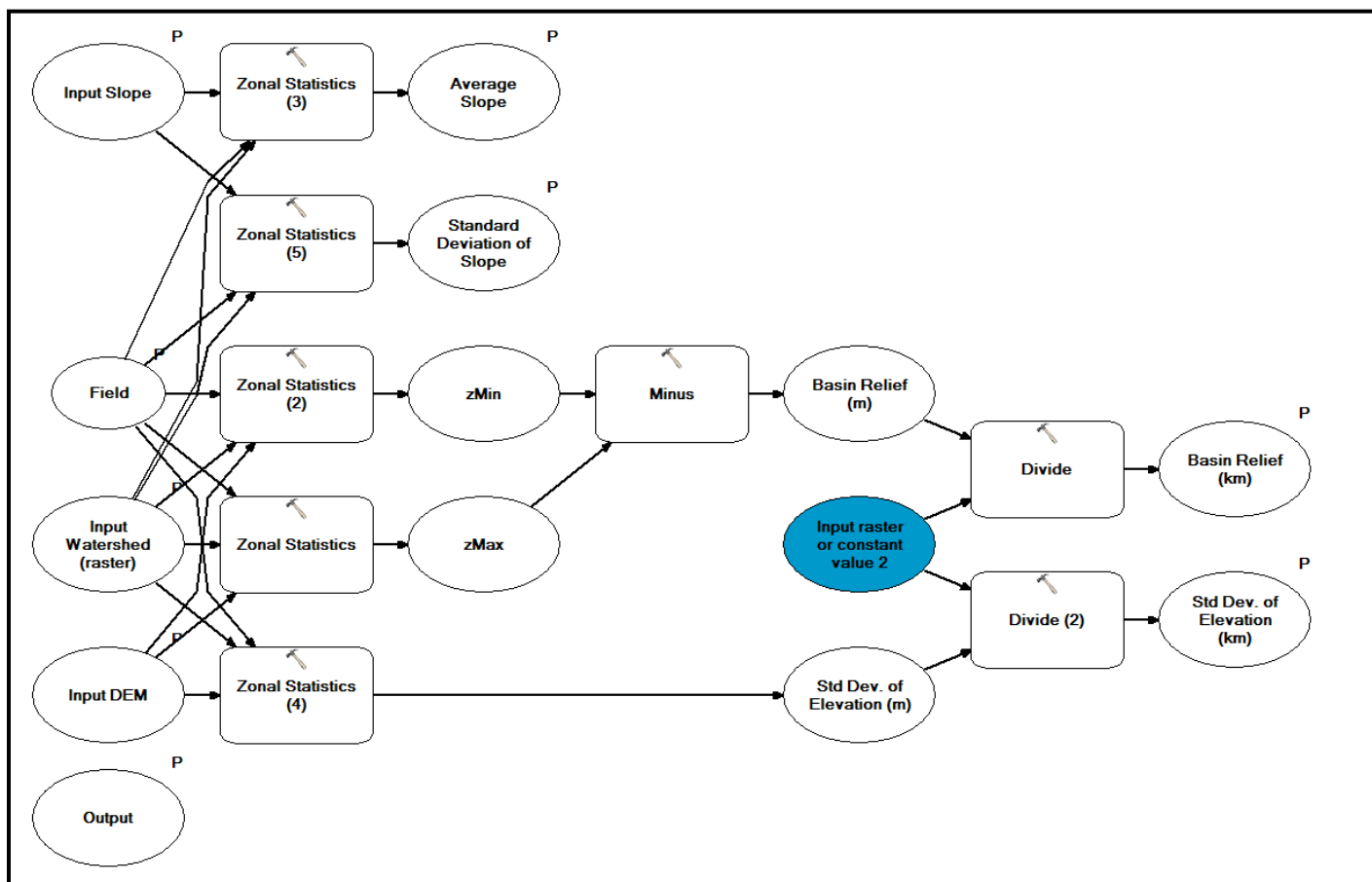


**Figure A-4.** Model for Watershed Characteristics Tool 4 – Watershed Relief and Slope.

## Appendix B – R Code to Create Land Use and Land Cover Tables

### R script

```
# Change for PARK/SITE
park <- "AGFO"
site.n <- "001"
day <- "20200612"

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

# Set working directory
setwd(paste("N:/Monitoring/Stream Channel/", park, "/Data/", 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),
  "2016" = round(t.2016[, 'Percent'], 3),
  "2019" = round(t.2019[, 'Percent'], 3)
)

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

```

## Appendix C – Watershed Delineation Method Using 20 ha Method in ArcPro

If the above methods fail, or you want confirmation of your output, you can follow the traditional stream network delineation directions. The traditional method is to use a regular DEM and the individual tools which make up the *Derive Stream As Line* tool.

1. Fill any holes in your DEM by using the *Fill* tool on your raster layer PARK\_SCM\_DEM\_proj\_ra, naming the output PARK\_SCM\_DEM\_filled\_proj\_ra.
2. Use the *Flow Direction* tool on PARK\_SCM\_DEM\_filled\_proj\_ra to create the output raster PARK\_SCM\_FlowDirection\_proj\_ra. Double check your snapped pour point is in NAD83(2011) Contiguous USA Albers projection.
3. Run the *Watershed* tool on PARK\_SCM\_FlowDirection\_proj\_ra and PARK\_SCM\_PourPoint\_snapped\_ra. Name the output PARK\_SCM\_Watershed\_fromDEM\_proj\_ra.
4. Confirmation of watershed general shape from old SOP 20 ha stream workflow
5. Run *Flow Accumulation* on the PARK\_SCM\_FlowDirection\_proj\_ra raster.
6. Name the output PARK\_SCM\_FlowAccum\_proj\_ra.
7. Determine the cell size of the Flow Accumulation raster.
8. Right click on layer, Properties>RasterInformation>Cell Size X –multiply Cell Size X by Cell Size Y.
9. Determine how many cells are in 20 ha. (20 ha= 200,000 square meters).
  - a. Example:  $10\text{m} \times 10\text{m} = 100$  square meters. And  $200,000 \text{ square meters} / 100 \text{ square meters} = 2000$ . In this case, use 2000 as the number value in the Expression parameter of the *Con* tool.
10. Run the *Con* tool on the PARK\_SCM\_FlowAccum\_proj\_ra raster. Expression:  $\text{Value} > 2216$  (if cell size is  $9.5\text{m}^2 \times 9.5\text{m}^2$  and there are  $200000\text{m}^2$  in 20 ha ).
11. Input constant value =1. Name the output PARK\_SCM\_FlowAccum[value used in Con tool]\_proj\_ra. The output is a raster stream network which hopefully confirms the shape of your final watershed.
12. Run *Raster to Stream* on PARK\_SCM\_FlowAccum[value used in Con tool]\_proj\_ra, naming the output PARK\_SCM\_Stream20ha\_[value used in Con tool]\_proj\_ln.

13. *Clip* this 20-ha stream lines layer to the watershed polygon so you can compare total stream length to NHD Flowlines.
14. Name the clipped layer PARK\_SCM\_Stream20ha\_[value used in Con tool]\_proj\_clip\_ln.  
(Example: MORU\_SCM\_Stream20ha\_2000\_proj\_clip\_ln.
15. Keep the unclipped layer as well to contrast to the outline of the watershed.