



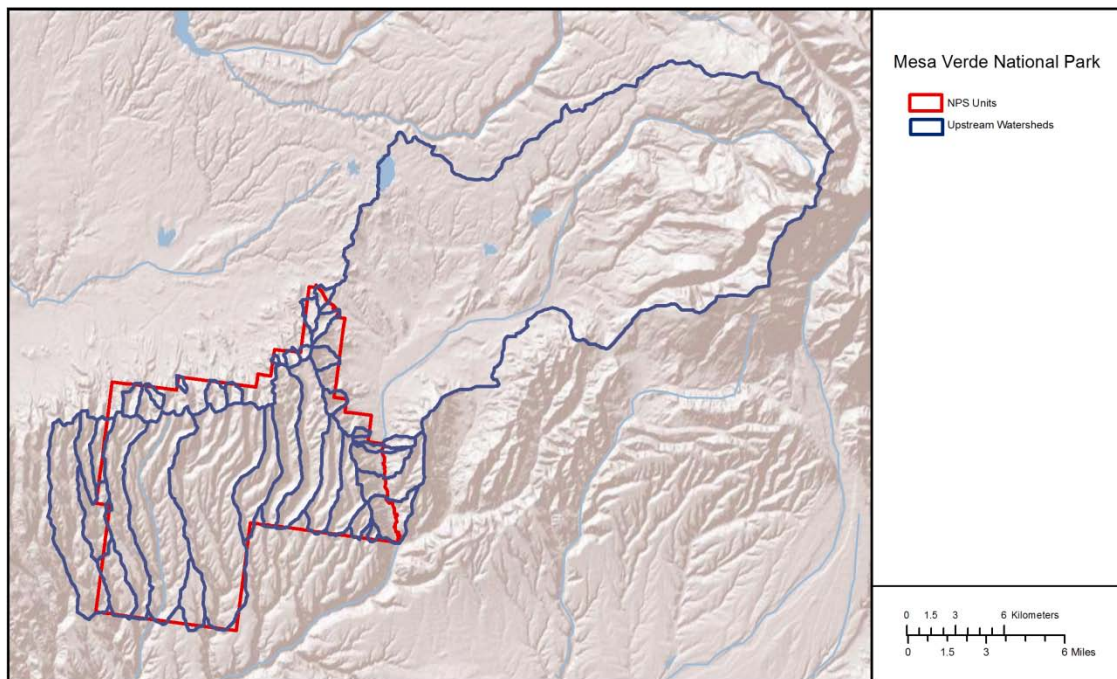
NOTE: This document reflects the processes used to generate the spring 2011 release of NPScape data. There may be revised processes and documentation available.

Check Reference Application (<http://nriminfo.nps.gov>) for most current version.

NPScape Upstream Watershed Delineation Processing SOP

Upstream Watershed Analysis for Select National Park Units

Version: 20110722



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1. Overview

This SOP provides guidance on how to process NPScape upstream watersheds for NPS park unit polygons or, more generally, other polygonal features. The upstream watershed process calculates 3 outputs:

- Pour point feature class representing the locations of streams and rivers intersecting with park (or polygon feature) boundaries
- 30 meter raster dataset of upstream watersheds derived from the pour points
- Polygon feature class of the upstream watersheds

Download the NPScape upstream watershed methods zip file from <https://nriminfo.nps.gov/Reference.mvc/Profile?code=2173077>. The zip file includes an ArcGIS toolbox containing an NPScape upstream watershed analysis script tool, an ArcMap document for displaying outputs, and a copy of this SOP document.

NPScape uses ArcGIS Spatial Analysis Hydrology tools to delineate watersheds. The Spatial Analysis Hydrology tools require Digital Elevation Models (DEMs) to provide base data to determine drainage basins or upstream watersheds (see especially Djokic and Ye 1999 for processing details). For NPScape, we used the NHD Plus dataset for the lower 48 states since the necessary flow accumulation and flow direction data inputs (derived from DEMs) are provided at 30 meter resolution (i.e., the same high resolution used for other NPScape metrics like land cover based on NLCD and CCAP).

Ye et al. (1999) describes the process of how to delineate upstream watersheds. In GIS course work of the University of Washington's school of Forest Resources, suitable examples of application are provided and discussed for the use of watershed delineation using elevation source data. Delineating watersheds are a way of dividing the land into manageable units to monitor the impacts of population on landscape health.

This document summarizes the methods used to generate upstream watersheds for any polygon of interest. Unless noted, the data sources and tools used are assumed to be in ESRI ArcGIS™ format, version 9.3.1 Service Pack 1, although the tool was tested in and runs in ArcGIS version 10.

2. Data Acquisition and Preprocessing

2.1. Source Data

Four datasets were used for processing the upstream watershed metrics of the lower 48 states: The National Hydrology Dataset Plus (NHD Plus) Flowlines, NHD Plus Flow Accumulation datasets, NHD Plus Flow Direction datasets, and a customized version of the NPS Current Administrative Boundary shapefile.

Example Sources for Lower 48 States Analysis:

- **Source 1:** NHD Plus Flowline Shapefiles

The NHD Plus Flowlines datasets are input datasets to determine “Pour point locations” or points where rivers and streams enter and exit park boundaries. *Note: These flowline features may need to be re-projected to match the spatial reference of the flow raster datasets.*

<http://www.horizon-systems.com/nhdplus/data.php>

- **Source 2:** NHD Plus Flow Accumulation Raster

The NHD Plus Flow Accumulation rasters are input datasets to determine high and low areas of water drainage accumulation and to snap the “pour point locations” to the appropriate cell with a high accumulation of flow.

<http://www.horizon-systems.com/nhdplus/data.php>

- **Source 3:** NHD Plus Flow Direction Raster

The NHD Plus Flow Direction rasters are input datasets to determine the direction of the flow accumulation, upstream vs downstream and to process the upstream watersheds from the pour point locations.

<http://www.horizon-systems.com/nhdplus/data.php>

- **Source 4:** NPS Current Administrative Boundary Shapefile

A customized version of this shapefile was used as a input with the flowline shapefile to determine “pour point locations” where streams enter and exit park boundaries. Non-customized version:

<https://nriminfo.nps.gov/Reference.mvc/Profile?Code=2170522>

The upstream watershed analysis tool can be run with different inputs, particularly the park (or other) polygon of interest. In this case, be sure the polygon’s spatial reference matches that of the NHDPlus flow raster inputs.

2.2. Re-Projection of Source Data

Each source dataset must be re-projected into a common spatial reference. For CONUS areas, the NPScape project uses USA Contiguous Albers Equal Area Conic USGS (NAD83) as its standard projection. A different spatial reference may be used as long as all 4 input datasets are projected to the same spatial reference.

3.0 Processing and Analysis

3.1. Step 1 – Choose Input Polygon(s)

The input polygon shapefile or feature class should contain the NPS park boundary or other polygon of interest for which upstream watersheds will be delineated. This polygon acts as the drainage ‘sink’ for the upstream watersheds; stream flow from those watersheds enters this polygon at the calculated pour point locations. If using the NPS

Current Administrative Boundary shapefile, select the park polygon of interest and export it to a new feature class or shapefile.

3.2. Step 2 – Mosaic Source Flowline Data

Depending on your area of interest, the source flowline shapefiles may need to be mosaicked. The NHD Plus flowline shapefiles come split into [hydrologic accounting regions](#) for the lower 48 states.

3.3. Step 3 – Mosaic Source Rasters

Depending on your area of interest, the source rasters may need to be mosaicked. The NHD plus rasters flow accumulation and flow direction rasters come split into hydrologic accounting regions for the lower 48 states.

3.4. Step 4 – Re-project Source Data

All input feature classes and raster datasets must be in the same spatial reference. If they are not, use ArcGIS™ to create re-projected versions of these sources:

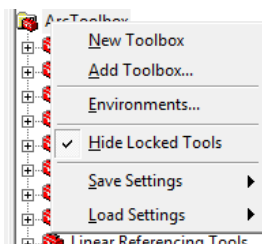
ArcToolbox → Data Management Tools → Projections and Transformations → Feature → Project

ArcToolbox → Data Management Tools → Projections and Transformations → Raster → Project Raster

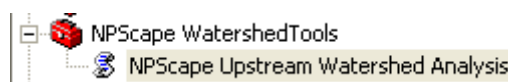
3.5. Step 5 – Perform Upstream Watershed Analysis

ArcGIS™ script tools with Python scripts are used to produce the upstream watershed outputs.

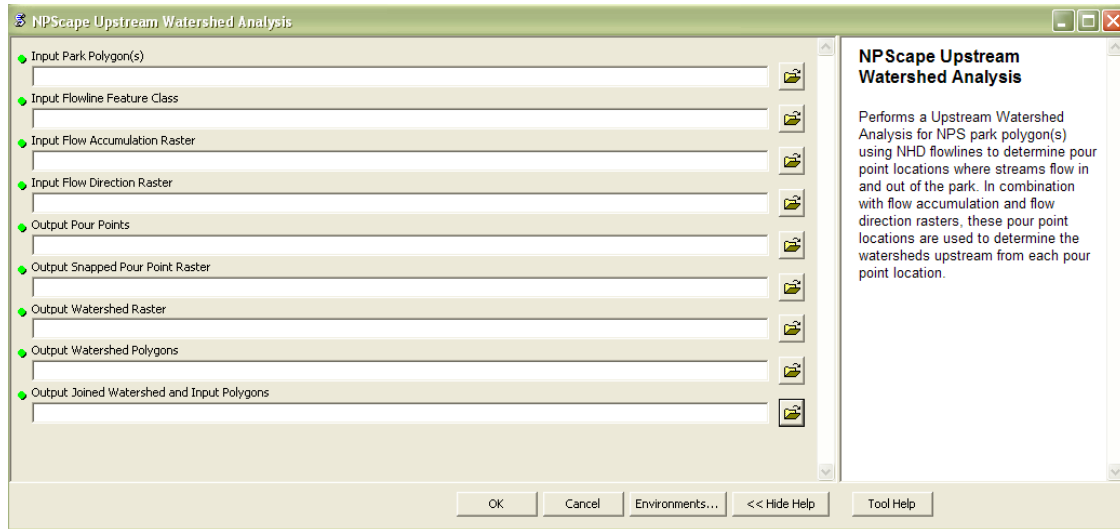
Open ArcMap and open ArcToolbox. Right-click on ArcToolbox and choose Add Toolbox...’.



Navigate to the folder where the methods zip file was unzipped. Select the NPScape Watershed.tbx file to add.



Open the NPScape UpstreamWatershed Analysis tool and enter the parameters as shown. Click the Environments button and set the General Settings and set the Extent option to “Same as the flow accumulation layer” Then, set the Raster Analysis Settings → Cell Size option to “Same as the flow accumulation layer”.



Upstream Watershed Analysis Parameters:

- **Input Park Polygon(s):** The NPS park boundary (or other polygon) feature class or shapefile used as the watershed ‘sink’ (drainage from upstream watersheds flows into this polygon).
- **Input Flowline Feature Class:** The NHD flowline shapefile/feature class used to generate pour points.
- **Input Flow Accumulation Raster:** The NHDPlus (or custom) flow accumulation raster dataset.
- **Input Flow Direction Raster:** The NHDPlus (or custom) flow direction raster dataset.
- **Output Pour Points:** Full path including name for the output pour point feature class or shapefile.
- **Output Snapped Pour Point Raster:** Full path including name for the output snapped pour point raster.
- **Output Watershed Raster:** Full path including name for the output watershed raster.
- **Output Watershed Polygons:** Full path including name for the watershed polygon feature class or shapefile.

- **Output Joined Watershed and Input Polygons:** Full path including name for feature class or shapefile containing the spatially joined upstream watersheds and input park (or other) polygon(s).

Depending on the size of the area of analysis, the script may take several hours to 2 weeks to run (the latter is the time it took to process upstream watersheds for all parks in the lower 48 states).

The tool's processing steps are:

- **Intersect flowlines with the park (or other) polygons, creating pour points.** Where each flowline crosses or intersects with a park polygon, a point will be created to determine locations where streams flow in and out of the parks.
- **Join attributes of the park polygon to the pour points feature class.** The watershed tool performs a spatial join on the attributes of the pour points by determining the pour points that intersect with a park polygon. The output indicates which pour points are associated with which parks and is used for attributing the upstream watersheds, as well as quality control.
- **Snap pour points to the input flow accumulation raster.** The pour points that were created in the previous step must be “snapped” or shifted to match the flow accumulation raster. When the pour point is snapped to the raster, the watershed tool uses a 60 meter search radius to find the closest high flow accumulation cell and then shifts the pour point to the high flow accumulation cells' centroid. The output for this step is a raster dataset where each pour point is represented by a cell.
- **Delineate watersheds upstream from the snapped pour points.** The final step of the watershed tool delineates the upstream watersheds using the snapped pour points created in the previous step and the NHD Plus flow direction raster. In this process, the pour points act as the start of high flow accumulation. Flow is then traced back upstream using the flow direction raster which determines the direction of drainage. The result is a raster dataset of upstream watershed(s) from the pour point(s).

4. Quality Control

4.1. Verify spatial and thematic integrity

Add the upstream watershed feature class and input park polygon feature class to ArcMap. Next, perform a Select by Location operation by selecting features of the upstream watershed feature class that intersect the input park polygons. Switch Selection to determine if there are any watershed polygons that do not intersect with the park polygon(s). If there are polygons that don't intersect, use the Eliminate tool found in Data Management → Generalization → Eliminate to remove them. Next, perform Select by Location and Switch Selection operations again. If there are still watershed polygons not

intersecting with the park polygon(s), use the Delete Features tool found in Data Management → Features → Delete Features to remove them.

Examples of parks with erroneous upstream watersheds:

Some of these errors are due to limitations of the source datasets and some are due to topology errors when converting the upstream watershed raster to a polygon feature class.

Big Cypress National Preserve (BICY)
Golden Spike National Historic Site (GOSP)
Olympic National Park (OLYM)

4.2. Special QAQC applied to NPScape geodatabase

The NPScape geodatabase of upstream watersheds does not contain polygons for all parks. Several data conditions had to be met in order for a park to be represented in the final geodatabase:

Condition 1: Parks were only considered if they were one of the 293 natural resource parks serviced by NPScape:

<https://nrinfo.nps.gov/Reference.mvc/Profile?Code=2170522>.

Condition 2: The number of pour points for a park had to be greater than the number of park subunits. This condition was imposed to ensure that the resolution of the flowline data was reasonable, given the size and distribution of the park.

Condition 3: Park subunits had to be on average at least 100 acres. As with condition 2, this condition was imposed to ensure that the resolution of the flowline data was reasonable, given the size and distribution of the park.

Condition 4: Parks were considered only if they had fewer than 10 subunits. Again, this condition was imposed to ensure that the resolution of the flowline data was reasonable, given the size and distribution of the park.

Condition 5: Parks could not be ocean, coastal, estuarine, or Great Lakes:

<https://nrinfo.nps.gov/Reference.mvc/Profile?Code=2167293>. This condition was imposed because it was determined that the hydrography of non-terrestrial parks was too complex for “upstream” delineations to be adequately captured by our processing tool and input source data.

Condition 6: Parks could not be Parkways or Trails. This condition was imposed because the large and long, linear nature of these parks created too much complexity for “upstream” delineations to be adequately captured by our processing tool and input source data.

Condition 7: Parks had to have at least reasonably complete flowline data. Parks in Alaska and the Hawaiian Islands had incomplete flowline data and were thus excluded from analysis. Also, CRMO and LABE in the continental U.S. appeared to have incomplete flowline data, or at least issues with the precision of the flowline data, and thus were excluded.

Condition 8: Finally, in an effort to eliminate upstream polygons originating from non-natural features, upstream polygons were deleted from a park if they contained a single pour point with an 'FTYPE' (NHD Plus flowline attribute) of 'Coastline', 'CanalDitch', or 'Pipeline'. This retained polygons with FTYPE = 'StreamRiver', 'ArtificialPath', and 'Connector'. The latter two categories needed to be retained in order to capture flow through waterbodies (see Caveat 4, below).

5. Important caveats

The proper use and interpretation of watersheds produced using this method require an understanding of several important caveats.

Caveat 1: The NPScape geodatabase of park upstream watersheds was created using the above method as applied to all NPS units. In other words, it was not run iteratively park-by-park. Importantly, this means that the upstream watersheds produced are those that are most proximate to a given park. Furthermore, the output does not capture in a hierarchical sense cases where a given park and its watersheds drain into another park. The above method could be run park-by-park to obtain fully inclusive upstream watersheds that are unconstrained by the spatial distribution of other NPS units.

Caveat 2: The precision of the watershed is heavily dependent on the precision of the input flowline, flow accumulation, and flow direction data. Flowlines are used to estimate pour points, so the absence of a stream in flowline data means the absence of a pour point, and possibly the omission of a watershed (if no other pour points within that watershed exist for other flowlines).

Caveat 3: NHD Plus flowlines do not distinguish among different stream types like ephemeral, perennial, etc. Hence, the NPScape geodatabase of upstream watersheds does not make these distinctions. If such distinctions are important, then focal watersheds will need to be recomputed from a flowline data source like NHD (not NHD Plus) that provides these attributes.

Caveat 4: NHD Plus uses center lines to preserve the flowline network through waterbodies like lakes and reservoirs. When these center lines do not align well with the actual lowest topographic points along the borders of the waterbodies, then upstream watersheds related to these waterbodies may be misrepresented in the calculations.

6. Literature Cited

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Horizon Systems Corporation, 2010. NHDPlus Users Guide.
<http://www.horizon-systems.com/nhdplus/documentation.php>

University of Washington, 2010. Surface Hydrologic Modeling and Watershed Delineation. <http://courses.washington.edu/gis250/lessons/hydrology/index.html>

7. Appendices

7.1. Known issues

Limitations of Watershed boundaries dataset

The automated delineation process used to create the NPS upstream watershed feature class efficiently generated watershed boundaries for most, but not all, NPS upstream watersheds. Limitations due to a variety of reasons, such as, elevation source data and flowline source data have reduced the amount of accurate watersheds and therefore, we have chosen the parks that are most suitable for this analysis.

Some known erroneous upstream watersheds for particular parks include areas of Everglades National Park (EVER) due to the complicated hydrological system of the area. Golden Spike National Historic Park (GOSP) also contained small errors due to the source 30 meter grids used to pre-process. Other errors may exist and we continue to correct this issues as they arise.

ArcGIS 10 Intersect tool errors

In ArcGIS 10, the Intersect tool used to generate pour points may assume the input flowline shapefile or feature class has Z or M values (i.e. is multi-dimensional). This will cause the Intersect operation to fail with a message of 'ERROR 999999: Error executing function. Invalid Topology [M coord limit exceeded.]'.

If this occurs, use the Feature Class to Feature Class conversion tool to create a new feature class. Set the following Environment settings: M Values Settings → Output has M Values = Disabled and Z Values Settings → Output has Z Values = Disabled.

7.2. NHDPlus DEM and flow raster details

NHD Plus HydroDEM data were created by using NED 30 meter digital elevation models (DEM). Modifications were applied to the DEMs to generate a HydroDEM. Occasionally, the drainage paths defined by the NED DEMs do not complete line up with the flowpaths of the 1:100,000 scale NHD flowlines. To integrate the stream locations in NED and the NHD vector flowlines, NHD Plus used a technique called “stream burning”. This process uses a AML program called AGREE developed by Hellweger (1997). This program “burns” a drainage into the NED DEM by subtracting a specific vertical distance from the elevation beneath the NHD Vector flowlines.

This process also smoothes the elevation cells that are adjacent to the NHD flowline cell locations in the DEM that are within a specified buffer distance. The buffer distance is determined from a common horizontal displacement error between NHD flowlines and NED-derived streams. For the HydroDEM, the buffer distance was set to 160 meters on each side of the NHD flowline. This smoothing process changes the elevations within the buffer area, creating a downward sloping gradient towards the stream location. The steepness of the slope in the buffer is determined by the drop/raise distance. A smooth drop distance of 500 meters was used for the HydroDEM.

Next, the HydroDEM was merged with the Watershed Boundary Dataset (WBD). This process is called “walling” and uses an AML written by Moore and Johnston (2004), to exaggerate the DEM elevations that correspond to the location of the WBD ridgelines. Breaks in the walls were created in areas where the flowlines cross the WBD, which allows passage of water from one WBD subwatershed to another.

Next, a bathymetric gradient was applied to the HydroDEM to ensure that catchments for artificial flowlines within waterbodies such as lakes and ponds have gradient that flows in the direction of the vector flowlines. This gradient was applied using GRID algorithms to create a sloping gradient with the shorelines upslope from artificial flowlines.

The last step for creating the final HydroDEM, was to “fill” the DEM. This is done by using the ARC/INFO GRID command “Fill” and removes depressions within the DEM surface. By performing the “FILL” command, it insures that the elevation cells have a defined drainage direction.

After the HydroDEM was created, the flow direction GRID can be processed using the HydroDEM. Using the FLOWDIRECTION command in ARC/INFO a new GRID is generated which contains cell values that represent the direction from each cell to its steepest downslope neighbor cell. Next, the flow accumulation GRID is generated by using the flow direction GRID as the input data, using the FLOWACCUMULATION command in ARC/INFO. The flow accumulation grid contains cell values equal the the number of cells which are uphill from that cell.