

Delineation of Watersheds

Adirondack Park, New York

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Introduction

Problem

Watershed boundaries are increasingly being used in land and water management, separating the direction of water flow such that all water within one watershed flows toward the same outlet point. Thus, a pollution source at the head of one watershed will not affect adjoining ones, but it will affect every location downstream within its own watershed. Delineating watershed boundaries helps managers monitor the amount and quality of water entering a point of interest, such as a stream, lake, or estuary.

Adirondack Park is a protected area in northeastern New York that encompasses more than 6 million acres (24,700 square kilometers [km²]), which makes it the largest park in the contiguous United States. Although protected, much of the park is privately owned land, which is used mostly for forestry, agriculture, and recreation. Given its size and variety of uses, it is important to understand the sources and flow of water in the park.

Location

Adirondack Park in northeastern New York State, USA

Time to complete the lab

One hour

Prerequisites

Advanced geographic information system (GIS) experience; ArcGIS® Spatial Analyst

Keywords: environmental studies; hydrology; watershed delineation; digital elevation model; raster data import; project; clip; mosaic; raster processing; Spatial Analyst extension; flow direction; filling sinks; water accumulation; source raster; stream links; data mashup

Data used in this lab

Data that can be downloaded or viewed online; three required datasets

- Adirondack Park boundary shapefile from the New York State GIS Clearinghouse at <http://gis.ny.gov/>
- A hydrology shapefile from Cornell University's Geospatial Information Repository (CUGIR) site at <http://cugir.mannlib.cornell.edu/index.jsp>
- A 30-arc-second digital elevation model (DEM) of North America accessed from the Esri web portal

Student activity

A watershed or drainage basin describes the area of land from which all surface waters (e.g., rain, melting snow or ice) converge at a single point. This point is the exit of the watershed and usually forms a stream or lake. Watersheds are important hydrologic and environmental units because all water within one watershed is connected. Thus, water pollution at one point in the watershed will affect the entire area downstream of that point and thus becomes an important issue in environmental restoration and protection. Since water always flows from the highest point to the lowest, watershed boundaries are defined as the ridges separating flow.

Project overview

This lab, geared toward advanced GIS users who have experience with raster data and using ArcToolbox™ and the Spatial Analyst extension, involves downloading required layers, using a dataset served online, processing the data (export, project, clip) into a coherent GIS database, and performing watershed analysis (raster processing).

Delineating watersheds requires several steps including filling so-called *sinks* in the elevation model, determining the direction of flow through each grid cell, identifying stream channels (accumulation of flow from several neighboring cells), and setting a flow threshold for stream identification.

This project is broken down into three steps: (1) data collection, (2) data processing, and (3) watershed delineation.

COLLECT DATA

- 1 Create a new folder in Microsoft Windows Explorer (you could do this from within ArcCatalog too) where you will store and process your GIS data.
- 2 Download the Adirondack Park boundary shapefile. Go to the New York State GIS Clearinghouse at <http://gis.ny.gov/>, click *GIS Data » List Data Sets by Data Set Name*, and search for a file called *Adirondack Park Boundary*. Download *adkParkPoly.zip*.
- 3 Unzip *adkParkPoly.zip* by either double-clicking it or using a zipping program such as WinZip or 7-Zip. This will extract *adkParkPoly*, a shapefile.
- 4 Download hydrology. Go to the Cornell University Geospatial Information Repository website at <http://cugir.mannlib.cornell.edu/index.jsp>, click *Map browse* and *Statewide Data*, and then search for *Hydrography Features of New York State* shapefile provided by NatlAtlas. Select *Download now*. This will give you another zipped file.
- 5 Unzip the *CUGIRxxxx.zip* folder and extract all of the data of the *hydrology* shapefile within the *36_hydrology_s* folder. (Note: You have to search down several layers.)

The digital elevation model will be added directly to your ArcMap™ session in a mashup, since the data is too big for download.

PROCESS DATA

- 1 In ArcCatalog™, check the projection information for all your data, the metadata, and dataset descriptions. You should find that
 - The Adirondack Park boundary shapefile is in universal transverse Mercator (UTM) Zone 18N NAD 1983 meters.
 - The *Hydrologic Layers* shapefile is in Latitude/Longitude NAD 1927.

To overlay the datasets later, they all need to be in the same projection. Use the projection from the park boundary shapefile. UTM is one of the standard projections used for regional-scale analysis in North America, so there is no need to change that.

- 2 In ArcToolbox, open *Analysis Tools » Proximity » Buffer* and add a 20 km buffer to the park boundary (linear unit) to create a larger cookie cutter for clipping the elevation dataset. This buffer will create smoother watersheds later and avoid some edge issues.

3 Project *hydrology* to the same coordinate system as the Adirondack Park boundary (Go to *Data Management Tools » Projections and Transformations » Feature » Project*). Import the projection from *adkParkPoly* and name the output *hydro_utm83.shp*.

4 Clip the streams in *hydro_utm83* to the park boundary polygon (not the buffered polygon) using *Analysis Tools » Extract » Clip*.

5 Save the Output Feature Class as *hydro_utm83c*.

Your clipped streams result should look similar to figure 1.

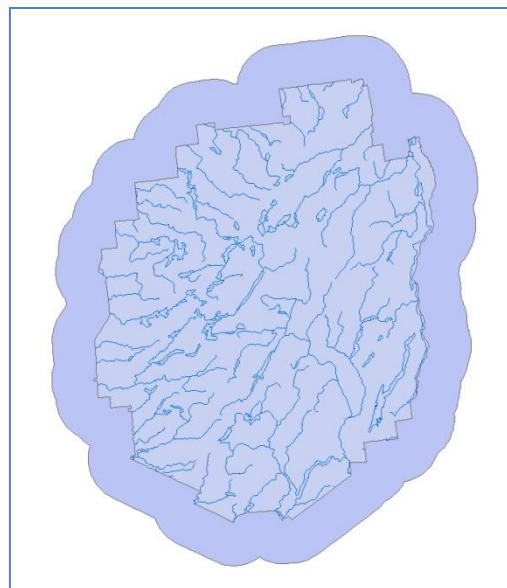


Figure 1: Major streams within Adirondack Park surrounded by a 20 km buffer zone.

6 Click the drop-down arrow on the *Add Data* icon and select *Add Data from ArcGIS Online*.

7 Type *DEM North America* into the search field and press Enter.

8 You will see *30 arc-second DEM of North America* as one of your returned datasets. Select it and click *Add*.

The DEM has a different projection from the park boundary and thus requires a transformation.

9 Click the *Transformations* button on the menu that pops up and then *convert from: GCS_WGS_1984* (the projection of the DEM *namer_DEM*) into *North America\NAD 1983*.

10 Click *OK* and *Close* on the next menu.

11 Clip *namer_DEM* to the buffered park boundary (*Data Management Tools » Raster » Raster Processing » Clip*).

12 Use the buffered park boundary as the output extent and scroll down to check *Use Input Features for Clipping Geometry* in the menu. Name the output Raster Dataset *DEMc*.

13 Remove the layer served online from your table of contents, since you have a local copy of your area of interest.

The outline of the DEM should show the same shape as the park buffer in figure 1. If your file has a rectangular shape, you did not use the clipping geometry.

Next, you will project the DEM into a more useful projection with metric ground units. The DEM originally is unprojected using the WGS 1984 datum. The file has a resolution of 30 arc seconds, which approximates 30 by 30 m pixel sizes.

- 14 Go to *Data Management Tools » Projections and Transformations » Raster » Project Raster*.
- 15 Make the Input Dataset *DEM* and name the Output Dataset *DEM_utm83*.
- 16 Import the coordinate system from *hydro_utm83*, which will set your output coordinate system to *NAD_1983_UTM_Zone_18N*.
- 17 Select the *WGS_1984 to NAD_1983* transformation, scroll down and choose *bilinear* for *Resampling Technique*, and set 30 m output cell sizes. If your computer is too slow to handle that, use a larger cell size, such as 60 m or 120 m, instead.
- 18 Set the display of your Layers data frame to UTM 83 so that everything displays appropriately.
- 19 Right-click the *Layers data frame* in the table of contents and go to *Properties » Coordinate System*.
- 20 Expand *Layers* (click the plus sign [+]), and then expand the list that has *_utm83* in its name so you can select *NAD_1983_UTM_Zone_18N* as your coordinate system.
- 21 Click *OK* and confirm that you want to use this coordinate system when prompted.
- 22 All your data of interest are now in the same coordinate system. Remove all non-UTM83 layers from your table of contents to avoid confusion.

DELINEATE WATERSHEDS

Watershed delineation requires several input datasets that need to be created first. These are flow directions, filled sinks, water accumulation, a source raster, and stream links.

- 1 First, calculate flow directions for each cell in your DEM (*Spatial Analyst Tools » Hydrology » Flow Direction*).

Note: If this part of your Toolbox is grayed out, make sure your Spatial Analyst Extension is checked (*Customize » Extensions*).

- 2 Use *DEM_utm83* as your input surface raster and specify an output flow direction raster (*flow_dir*), but leave the output drop raster blank.

The resultant layer will be mostly gray and black with white dots all over and values ranging from 1 to 255.

Next, check for sinks. Sinks represent depressions (real or erroneous) in your data that impede water flow and therefore must be removed.

- 3 Determine sinks using *flow_dir* as your input and *sink* as your output (*Spatial Analyst Tools » Hydrology » Sink*).

The resultant layer will have values ranging from 1 to 3,838.

Now you need to fill the sinks by raising their elevations to equal neighboring cells so that water can continue flowing across them.

- 4 Fill the sinks (*Spatial Analyst Tools » Hydrology » Fill*). Use *dem_utm83* as your input and name your output *filled*. This layer should have values ranging from 26 to 1,482.

- 5 Determine flow directions for your filled DEM (*Spatial Analyst Tools » Hydrology » Flow Direction*). Your input here is *filled*; name the output *flow_dir2*. Since water

always flows from high values to low values, this layer should look similar to the DEM (figure 2).

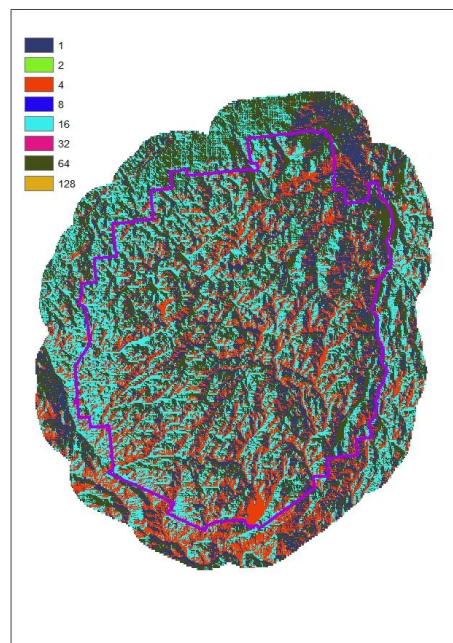


Figure 2: The *flow_dir2* layer shows flow directions after sinks were filled in; the purple line represents the Adirondack Park boundary.

- 6 To determine where water accumulates and creates channels, go to *Spatial Analyst Tools » Hydrology » Flow Accumulation*.
- 7 Use *flow_dir2* as input and *flow_acc* as output. Change the output data type to integer before clicking OK. The new layer values should range from 0 to $7.9e^6$ (nearly 8 million).
- 8 Invert the color scheme (right-click *flow_acc* in the table of contents, go to *Properties » Symbology*, and select a different color ramp that goes from white to black) before viewing the raster layer.

You can just barely make out the stream channels.

- 9 Create a source raster that will later serve as the input for watershed delineation. This requires choosing a threshold on the minimum number of cells flowing into any cell before it is designated as a stream cell. This value ultimately determines the size and number of watersheds delineated and must be chosen carefully. Start with 50,000, but feel free to try others. If your computer cannot handle this much data, choose a larger value.

- 10 Go to *Spatial Analyst Tools » Conditional » Con*; choose *flow_acc* as the input conditional raster layer, type *value > 50000* in the expression box, use *1* as your input true raster value, and call the output *net_50k*. The resultant layer will show faint stream channels.

- 11 Assign unique identifiers to each stream reach, which are stream sections between intersections (*Spatial Analyst Tools » Hydrology » Stream Link*). Use *net_50k* as the input stream raster and *flow_dir2* as your input flow direction raster, and name the output raster *source*.

This raster layer will only show a few gray dots that roughly resemble stream channels and range in value from 1 to 388.

- 12 You are finally ready to delineate watersheds. Go to *Spatial Analyst Tools » Hydrology » Watershed*, use *flow_dir2* as your input flow direction raster, choose *source* as the input raster, and name the output raster *watershd_50k* (figure 3).

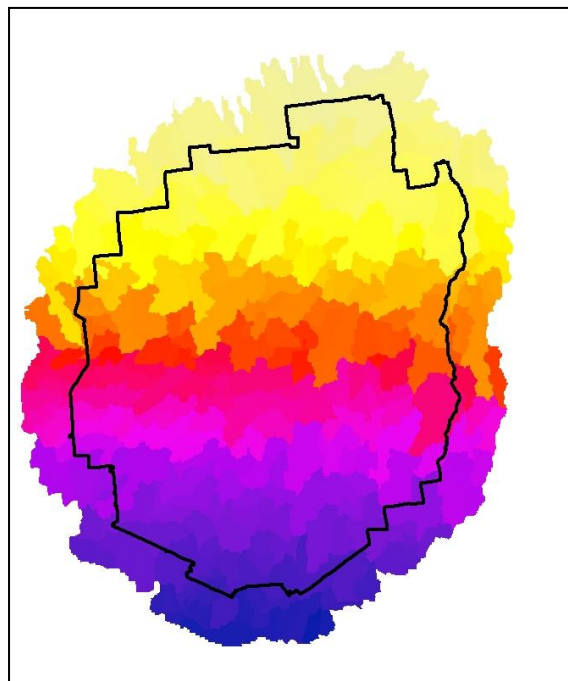


Figure 3: A 20 km park buffer zone and a threshold value of 50,000 for the minimum number of cells flowing into a stream result in 388 unique watersheds.

You should get 388 unique watersheds (values ranging from 1 to 388).

- 13 Clip the delineated watersheds *watershd_50k* to the park boundary *bdry_utm83*, since that is your actual area of interest (*Data Management Tools » Raster » Raster Processing » Clip*). Make sure to check *Use Input Features for Clipping Geometry* for the park boundary file.
- 14 Add the stream shapefile as blue lines and visually compare watershed boundaries with stream locations (figure 4).

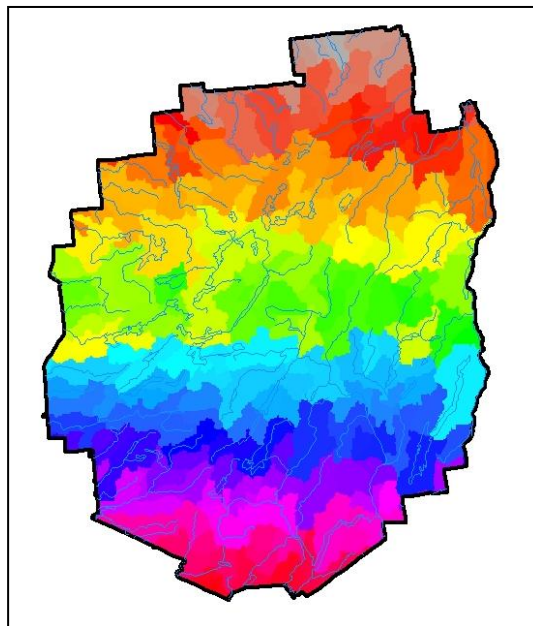


Figure 4: Major streams and final watersheds within the Adirondack Park boundary.

Conclusion

The total number of watersheds delineated in this analysis depends on several factors—most importantly, the threshold value set.

How many watersheds did your analysis yield? If you change your source raster threshold to 100,000 or 500,000, how many watersheds do you get?

How many watersheds do you consider a useful result of this analysis? What about the area that cannot be assigned to a watershed because the ridgeline cannot be connected?

FURTHER ANALYSIS

Repeat the analysis using the actual park boundary instead of the buffer; how do the results vary? Which result do you find more useful, the one with or without the buffer zone? Now that you have watersheds delineated, you can calculate total stream outflow from each watershed, assuming a constant rate of precipitation per unit area, for many other applications.

Credits

Images

Figures 1–4: Data derived from National Atlas of the United States of America and U.S. Geological Survey.

Instructor resources

Updates for 2013

The exercise was revised to reflect changes in the availability of the Adirondack park boundary (formerly the blueline). The file was previously available as an e00 file in NAD 27, but is now available as a shapefile in NAD83, thus eliminating the needs for unzipping, e00-import and transformation. Otherwise, minor edits were done to the text to improve clarity.

Additional information

The United States Geological Survey (USGS) provides information on major watersheds and hydrologic unit (HUC) datasets within the United States. One useful website on hydrologic units is <http://water.usgs.gov/GIS/huc.html>. The smallest scale these datasets are available at is 1:250,000. However, for smaller regions, such as the Adirondacks, the data still needs to be created. The same is true for areas outside the United States where detailed hydrologic information is hard to find.

The watershed delineation commands have detailed explanations stored in the ArcGIS command help menu. Another very helpful source is Chang's (2010) chapter on viewsheds and watersheds, because it provides detailed step-by-step instructions on data processing.

References

Chang, K. T. *Introduction to Geographic Information Systems*. Chapter 14, "Viewsheds and Watersheds." New York: McGraw Hill Higher Education, 2010.