

Demo 12: Hydrological modeling

Surface water is a critical resource for humans, animals, and agriculture. In this lab, you will learn how to model surface hydrology using a digital elevation model (DEM). In many ways this is a continuation of last week's lab on Spatial Modeling, but in this case most of the analyses are standardized in the ArcToolbox. You will then use the hydrological model you create to estimate erosion risk in your study area.

I. Prepare the Demo data

- a. There is a **Demo12_Data.zip** file. You should download it, although it only contains two layers.
 1. **SRTM_Michiana.tif** is the DEM I will use in the Demo
 2. **St_Joseph_erisk.dbf** you can use in the optional assignment
- b. For the demo and the assignment, this larger SRTM_Michiana DEM, If you mess up and use the one from last week, that is ok, I will accept either.
- c. Start a new ArcMap document and add the DEM (**SRTM_Michiana.tif** or yours). You do not need anything else.
- d. Before proceeding, make sure you enable the Spatial Analyst tools by going to **Customize** → **Extensions** and checking the box next to Spatial Analyst

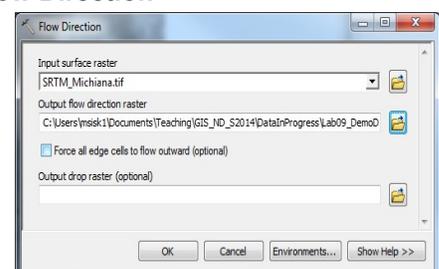
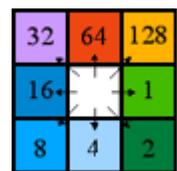
II. Basic order of hydrological modeling

- a. Remember from the lecture that there is a specific order in which you should do these tasks
 1. Check the DEM for **Sinks**. Or areas into which water flows in, but not out
 2. If necessary, **Fill these Sinks**
 3. Create a **Flow Direction** raster from a sinkless DEM
 4. Create a **Flow Accumulation** raster
 5. Convert the Flow Accumulation into a **Stream Raster**
 6. Calculate the **Stream Order**
 7. Convert the raster into a shapefile with **Stream to Feature**
 8. Isolate and correct **Pour Points**
 9. Calculate the **Watersheds** contributing to each pour point
- b. In most analyses, and for the purposes of this demo, these tasks can be split into two sections
 1. *Creating a Stream Network*
 - i. Analysis across the whole surface.
 - ii. This includes analyzing flow directions and accumulation, ordering and creating stream features.
 2. *Measuring flow at particular points*
 - i. Using the data from the stream network to analyze flow at key locations
 - ii. Creating pour points and analyzing the watersheds that contribute to them.
 - iii. Calculating the distance of water flow at particular points

III. Creating a Stream Network

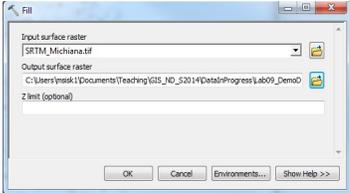
a. Flow Direction

1. The first step in modeling hydrology is to determine for each pixel the direction in which water would run off, called Flow Direction.
 - i. The values of the output grid are coded by direction.
 - ii. These values are the powers of 2 from 0-7: 1, 2, 4, 8, 16, 32, 64, 128
2. This first run is to see if there are any problems apparent. Most often, you will recreate the DEM with the sinks filled and rerun the Flow Direction on that image.
3. In ArcToolbox, select **Spatial Analyst Tools** → **Hydrology** → **Flow Direction**
 - i. The **Input surface raster** is the DEM:
 - a. Here **SRTM_Michiana.tif**
 - ii. The **Output Flow Direction** raster is what you create
 - a. Call it **Michiana_FlowDir_RAW.tif** and make sure to save it permanently



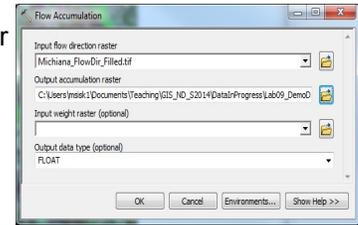
- iii. Leave Output Drop Raster blank
 - iv. Do not check "Force all edge cells to flow outward (optional)"
 - v. Click OK
4. The output grid is very similar to the Aspect of a DEM.
 5. You will notice a lot of values other than the ones that represent directions (1, 2, 4, 8, 16, 32, 65, 128). These represent areas for which the Flow Direction cannot be resolved.
 6. If there are more than a few you definitely want to fill the sinks.
 - i. Here, there are lots. Most notable are the flat water areas

b. Finding and filling sinks

1. Next, we will fill all of the sinks in the DEM. A sink is a pixel or group of pixels where flow direction runs in but cannot run out; for example, a pixel is lower than the eight pixels that surround it. Sinks may be real features (such as a lake or kettle) or errors in the DEM (especially if they are single pixels).
 2. Identify the sinks
 - i. In ArcToolbox, select **Spatial Analyst Tools** → **Hydrology** → **Sink**
 - ii. The **Input Flow Direction Raster** the raw Flow Direction layer from before
 - a. Here, it is **Michiana_FlowDir_RAW.tif**
 - iii. Save it in a permanent location and call it **Michiana_Sinks.tif**
 - iv. Click OK.
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3. Evaluating identified sinks
 - i. You may need to turn off the other layers to see the Sinks raster.
 - ii. In the sink raster (here, Michiana_Sinks.tif), each sink has a unique ID number. You can use the Identify tool to see the codes for each. All other pixels have a value of NoData, so they are transparent
 - iii. In the example data there are lots (nearly 12,000), so they appear as stretched (with a color ramp).
 - a. If you do not have many, they may appear with unique colors.
 - iv. In a more sophisticated analysis, one would identify the real sinks and then interactively fill in the non-real ones. However, for the purposes of this lab, we will simply fill in *all* sinks in the DEM.
 4. Fill all sinks
 - i. In ArcToolbox, select **Spatial Analyst Tools** → **Hydrology** → **Fill**
 - ii. Use the original DEM as the **Input Surface Raster**;
 - a. Here, **SRTM_Michiana.tif**
 - iii. The Output Surface Raster is the new DEM
 - a. Here call it **Michiana_DEM_Filled.tif**
 - iv. Leave the **Z-limit** blank
 - v. In the new DEM, where the elevation values of the former sink pixels has been increased so that flow now points out of them.
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5. Create a new Flow Direction layer
 - i. Follow the same process as in **Section III.a.** using the new DEM with filled sinks
 - ii. In ArcToolbox, select **Spatial Analyst Tools** → **Hydrology** → **Flow Direction**
 - a. The **Input surface raster** is the new DEM: **Michiana_DEM_Filled.tif**
 - b. The **Output Flow Direction**: **Michiana_FlowDir_Filled.tif**
 1. Make sure to save it permanently
 - c. Click OK
 - iii. This is the layer you will be using from now on.
 6. You will no longer use either the original DEM (**Michiana_SRTM.tif**) or the original Flow Direction raster (**Michiana_FlowDir_RAW.tif**) so you can remove them from the Table of Contents.
 - i. Before you remove them, you may want to look at the assignment, you will need to take a few screenshots using them.

c. Flow Accumulation

1. This creates a raster where each pixel's value represents the number of pixels that drain into it.
2. In ArcToolbox, select **Spatial Analyst Tools** → **Hydrology** → **Flow Accumulation**
 - i. **Input Flow Direction Raster** is the filled Flow Direction raster
 - a. Here, it is **Michiana_FlowDir_Filled.tif**
 - ii. The Output Accumulation Layer is the new Flow Accumulation
 - a. Call it **Michiana_FlowAccum.tif** and save it permanently.
 - iii. Leave the Input weight raster blank and the Output Data Type as **FLOAT**
 - iv. Click **OK**.
 3. To display the Flow Accumulation layer more clearly, go into its Symbology tab in Layer Properties and change the Stretch to Standard Deviations with $n = 0.25$.

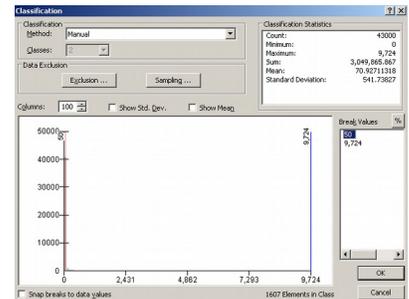


d. Creating a Stream Raster

- i. Ultimately, we intend to create a vector layer which models drainage in the form of polylines.
- ii. If we continue to use the Flow Accumulation layer as it is, we will create a vector layer that models drainage for every single pixel of the DEM. We could later remove any unwanted data.
- iii. For the sake of efficiency, it is better at this point to **Threshold** our Flow Accumulation raster so that it only includes areas with significant drainage flowing through them.
- iv. This will create a Stream Raster, a raster image with no data in areas without much drainage.
- v. In this case, let us assume that we are only interested in drainage that captures runoff from at least 50 pixels
 - a. This is 45,000 square meters (a little less than half a square kilometer) in a 30 meter DEM.
 - vi. There are many ways to do this in ArcGIS. I will outline two of them. For the assignment, you will choose one of the following two methods.

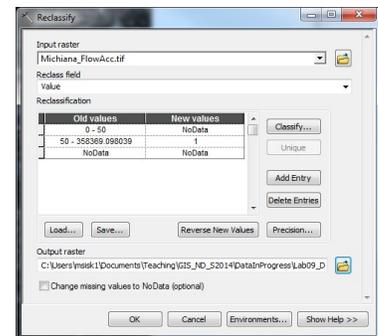
1. The first option uses the Reclassify tool that we used last week.

- i. Open the Layer Properties for **Michiana_FlowAccum.tif** by double-clicking on it in the Table of Contents.
 - a. This is a shortcut for the Reclassify that lets us see the results in advance
 - b. In the **Symbology** Tab change it from **Stretched** to **Classified**
 1. If you are asked to create a histogram, click **OK**.
 - c. Change the **Number of Classes** to 2 and click on the **Classify** button
 - d. In the new window, click on the first of the two values under **Break Values** in the lower right corner and change it to **50**
 - e. Click **OK** twice.



ii. In ArcToolbox, select **Spatial Analyst Tools** → **Reclass** → **Reclassify**

- a. The input raster is **Michiana_FlowAcc.tif**
- b. The Reclassify window will automatically adopt the classification you just set in the layer's Symbology tab
- c. In the New values column, set the values for 0 – 50 to **NoData** and 50 and higher to **1** (see the window to right).
- d. Leave everything else as is
- e. Call the Output Raster **Michiana_StreamRaster.tif** and save it to your permanent drive.
- f. You may want to take a screenshot before clicking **OK**, this is part of the assignment
- g. If you end up with weird ghost values, just increase the maximum value beyond the default value and rerun

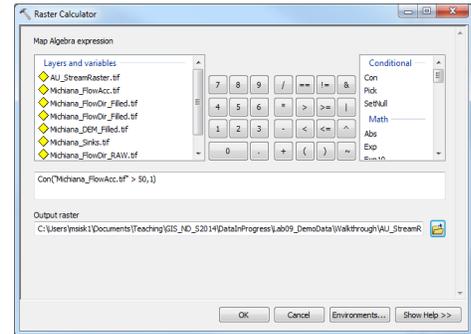


2. The other option uses the Raster Calculator with the Conditional function as outlined in class
 - i. In ArcToolbox, select **Spatial Analyst Tools** → **Map Algebra** → **Raster Calculator**

a. You want your equation to be:

Con("Michiana_FlowAccum.tif" > 50, 1)

1. This will examine each pixel of Michiana_FlowAccum.tif to see if its value is larger than 50.
 - i. If yes, it gets a value of 1
 - ii. If no, it gets a value of NoData
2. As usual, you are better off clicking the buttons to make the equation than trying to type it in.
3. The Con function is in the top right window



- b. Call the Output Raster **Michiana_StreamRaster.tif** and save it to your permanent drive.
- c. You may want to take a screenshot before clicking OK, this is part of the assignment

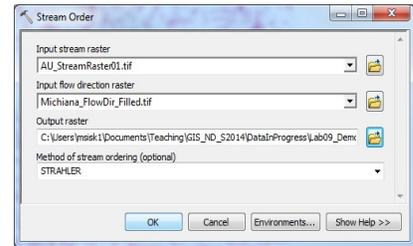
3. Regardless of which method you choose, you should have a stream raster layer that only has values for areas that have a lot of water flow.
4. It should roughly look like a stream system.

e. Creating a Stream Order grid

1. The Stream Order uses the flow direction (from Section III.b.6) and Stream raster (from Section III.d) to assign a rank to the linear arrangements of streams. It is the final step before creating a stream shapefile

2. In ArcToolbox, select **Spatial Analyst Tools** → **Hydrology** → **Stream Order**

- i. **Input Stream Raster** is the result of Section III.d
 - a. Here, it is **Michiana_StreamRaster.tif**
- ii. **Input Flow Direction** is the result of Section III.b.6
 - a. Here it is **Michiana_FlowDir_FILLED.tif**
- iii. Output raster is your new Stream Order layer
 - a. Call it **Michiana_StreamOrder.tif** and save it to your permanent drive.
 - b. In previous versions of the software, this did not work and instead came out with all values of 1
 - c. If this happens to you
 1. Try leaving it as temporary
 2. Or saving it as an ESRI Grid format (not a tif) called Mich_StrOrd
 3. You can then export either of these to Michiana_StreamOrder.tif
- iv. Leave the method of stream ordering as **STRAHLER** and click OK.

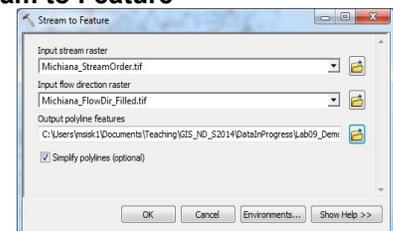


3. The output raster pixel values correspond to the ranking of the stream in the Strahler system of stream ordering.
 - i. Make very sure that you have a series of values, here from 1-6
 - ii. *Again, if all you have is 1's then try again using the suggestions in III.e.2*

f. Creating a Stream Shapefile

1. You can create a polyline shapefile of where the streams are likely to be, based on the Stream Order grid.
2. In ArcToolbox, select **Spatial Analyst Tools** → **Hydrology** → **Stream to Feature**

- i. **Input Stream Raster** is the Stream Ordered Grid result of Section III.e
 - a. Here, it is **Michiana_StreamOrder.tif**
- ii. **Input Flow Direction Raster** is the result of Section III.b.6



- a. Here it is **Michiana_FlowDir_FILLED.tif**
- iii. Output the polyline features to a shapefile
 - a. Call it **Michiana_DrainagePaths.shp** and save it to your permanent drive.
- 3. Classify the resulting polyline layer to make it more comprehensible; for example, the larger streams/drainages can be symbolized with a thicker line than the smaller (more ephemeral) drainages.
 - i. In the **Symbology** tab, show **Quantities** and then select **Graduated Symbols** based on the Value Field **GRID_CODE**;
 - ii. If see a message that “Maximum sample size reached...”
 - a. To raise the maximum sample size, click OK and then click Classify...
 - b. Under Data Exclusion, click Sampling...
 - c. Change the Maximum Sample Size to 500000 and click OK.
 - iii. In the Classification window, select Defined Interval as the classification method, and set the interval size to 1. Click OK.

IV. Drainages of individual points

- a. In this section, you will both calculate the flow length for each pixel of the DEM and outline the area that drains into individual points of interest. Both of these are useful measures for understanding the volume of water passing over a particular point.

b. Flow Length

- 1. This tool calculates a raster image that represents how far water from each pixel would flow before reaching the edge of our data
- 2. In ArcToolbox, select **Spatial Analyst Tools** → **Hydrology** → **Flow Length**

i. Input Flow Direction is the result of Section III.b.6

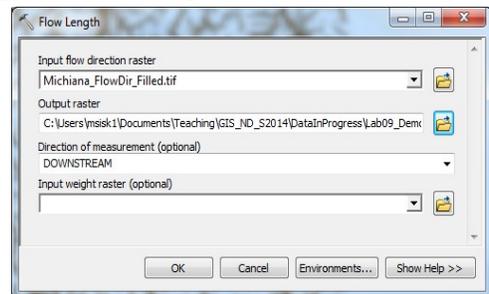
- a. Here it is **Michiana_FlowDir_FILLED.tif**

ii. Output Raster is the new Flow Length measurement

- a. Call it **Michiana_FlowLength.tif** and save it to your permanent drive.

iii. Direction of Measurement

- a. **Downstream** calculates the distance along the flow path to a sink or the edge of the raster. This is the default and what we want to use here.
- b. **Upstream** calculates the longest upslope distance along the flow path, from each cell to the top of the drainage divide



- iv. Leave Input Weight Raster blank and choose OK to run

c. Basins

- 1. The Basin tool will divide the entire area into watersheds. It does this by placing pour points along the margins and in sinks to catch all of the flow.

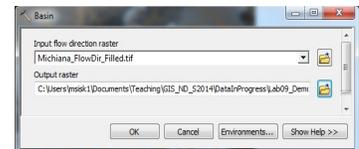
- 2. In ArcToolbox, select **Spatial Analyst Tools** → **Hydrology** → **Basin**

i. Input Flow Direction is the result of Section III.b.6

- a. Here it is **Michiana_FlowDir_FILLED.tif**

ii. Output Raster is the raster classified into basins

- a. Call it **Michiana_Basins.tif** and save it to your permanent drive



- 3. There are often a lot of very small basins around the edges of these images. Using the “Force all edge cells to flow outward” option when creating the Flow Direction will mitigate this.

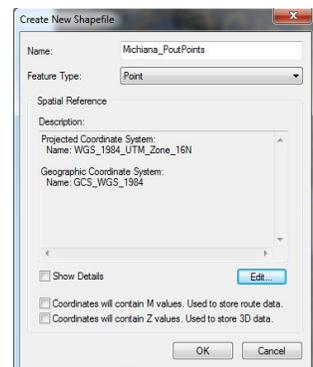
d. Watersheds

- 1. Often you want to calculate the drainage area that flows into a certain location. This tool lets us do so.

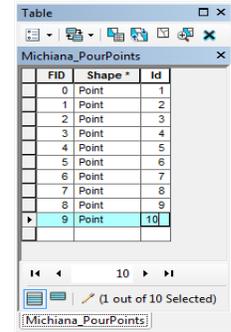
- 2. In order to run it, we first need a series of Pour Points.

3. Create the Pour Points

- i. Create the new shapefile.

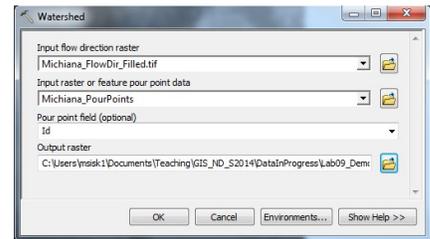


- a. In the Catalog Tab, navigate to your Lab10 folder
 - 1. This process is outlined in more detail in the Week 6 Demo
- b. Right click on the folder name and choose **New** → **Shapefile**
- c. Name it **Michiana_PourPoints.shp**
- d. Leave the Feature Type as Points **Shapefile**
- e. Update the Spatial Reference to **UTM WGS1984 Zone 16N**.
- f. Click OK and you should have the new shapefile in your Table of Contents.
- ii. Start editing **Michiana_PourPoints.shp**
 - a. Right click on the layer name in the Table of Contents
 - b. Choose **Edit Features** → **Start Editing**
 - c. Choose **Michiana_PourPoints** in the Create Features window that pops up.
 - d. Verify the Point ( Point) is selected under Constriction tools.
- iii. Create around 10 features across the extent of your study area
 - a. Put them in areas that you think will have large amounts of water flow.
 - b. These are easy to find if your Drainage Paths shapefile (**Michiana_DrainagePaths**) is visible, but for this example it is better to have it off so the points will not snap directly onto it
- iv. Edit the ID field so each has a unique ID
 - a. While editing, right click on **Michiana_PourPoints** in the Table of Contents and choose **Open Attribute Table**
 - b. Change the ID field to be unique numbers (likely 1 -10).
 - c. This is required for the analysis, so make sure you change them
- v. Stop Editing
 - a. In the Editing Toolbar choose **Save Edits** and then **Stop Editing**.

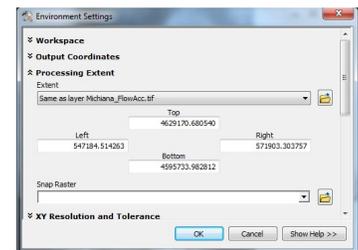


4. Create the Watershed for each point

- i. In ArcToolbox, select **Spatial Analyst Tools** → **Hydrology** → **Watershed**
 - a. **Input Flow Direction** is the result of Section III.b.6
 - 1. Here, it is **Michiana_FlowDir_FILLED.tif**
 - b. **Input Raster or Feature Pour Point Data** is the new pour points shapefile
 - 1. Here, it is **Michiana_PourPoints.shp**
 - c. The **Pour Point Field** gives each pour point its identifier
 - 1. For this shapefile it is **ID**
 - d. **Output Raster** is the raster classified into watersheds for each point
 - 1. Call it **Michiana_Watersheds_RAW.tif** and save it to your permanent drive



- ii. Before running the tool, click the **Environments...** button
 - a. Under **Processing Extent**, make sure the **Extent** is set to be the same as one of the various DEM-derived raster layers, for example, **Michiana_FlowAccum.tif**. (Otherwise, the output extent is set by default to be the extent of the pourpoints layer, which is smaller.)
 - b. Click OK to return to the Watershed tool.
- iii. Click OK to run the Watershed tool.
- iv. Your output will be like the Basin tool, except that it will only cover the area that flows into each Pour Point.
 - a. You could now convert this into a shapefile and calculate the area drained through each Pour Point.



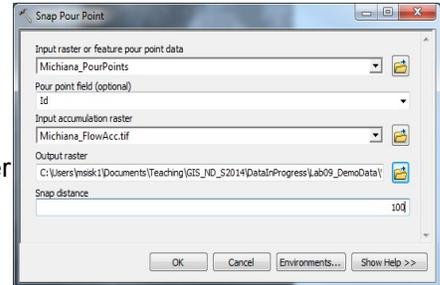
5. Snap Pour Points

- i. For each drainage, water accumulates and flows through just one cell.

- ii. In the real world, your pour points will be from GPS coordinates or other non-perfect sources and the chances of them being in this cell are slim.
- iii. In these cases, an estimate of the highest accumulation within a small search radius will give a better estimate of how much water flows through the area.
- iv. The Snap Pour Points tool does this systematically by moving the pour points to the nearby location with the highest accumulation.

- v. In ArcToolbox, select **Spatial Analyst Tools** → **Hydrology** → **Snap Pour Points**

- a. **Input Raster or Feature Pour Point Data** is the pour points shapefile
 - 1. Here, it is **Michiana_PourPoints.shp**
- b. The **Pour Point Field** gives each pour point its identifier
 - 1. For this shapefile it is **ID**
- c. **Input Accumulation Raster** was calculated in Section III.c
 - 1. Here, it is **Michiana_FlowAccum.tif**
- d. **Output Raster** is a raster version of the pour points moved to the optimum location
 - 1. Call it **SnappedPP** and save it to your permanent drive
 - i. ***It is important that you do not save it as a tiff here. It will make a massive error if you do, so call it SnappedPP without the .tif***
- e. **Snap Distance** is the maximum distance in map units that the points can be moved
 - 1. Here, make it **300** (about 10 pixels in a 30 m resolution image)
 - 2. If you are using your smaller park data, maybe try making it 100
- f. Choose OK to run it



- vi. This will have created a raster layer with only a few visible cells. If you zoom way in on the points of

6. Rerun the Watershed with the Snapped Pour Points

- i. You should now rerun the watershed analysis with this raster and compare the results.
- ii. Follow Section IV.d and open the Watershed Tool
 - a. **Input Flow Direction** is the result of Section III.b.6
 - 1. Here, it is **Michiana_FlowDir_FILLED.tif**
 - b. **Input Raster or Feature Pour Point Data** is the new pour points raster
 - 1. Here, it is **Michiana_SnappedPP.tif**
 - c. The **Pour Point Field** gives each pour point its identifier
 - 1. For this raster it is **Value**
 - d. **Output Raster** is the raster classified into watersheds for each point
 - 1. Call it **Michiana_Watersheds_SNAP.tif** and save it to your permanent drive
- iii. Again, before running the tool, click the **Environments** button and set the extent to the DEM or one of its results.
- iv. Compare this later to **Michiana_Watersheds_RAW.tif**. The new layer should have larger watershed areas because of the optimized pour points.