Lab 6: Rasters Part 2 (Hydrology, Watersheds, and Precipitation Interpolation)

Introduction

The May 27, 2018 Ellicott City flood was caused by a highly localized, extreme precipitation event centered over the steep, confined catchments of the Tiber, Hudson, and New Cut river branches. Evaluating this hazard requires modeling both the topographic routing of the water and the spatial distribution of the rainfall.

In this lab, you will process a bare-earth Digital Elevation Model (DEM) using standard hydrologic algorithms to extract flow paths and delineate the exact contributing watershed areas for Ellicott City's historic district. You will explore how the land cover within these watersheds affected downstream flooding. You will then interpolate point-based rain gauge data into a continuous precipitation surface. By combining the delineated watersheds with the interpolated rainfall, you will quantify the specific volume of water deposited into the upstream catchments.

Learning Goals

By the end of this lab you will be able to:

- Condition a DEM and generate Flow Direction and Flow Accumulation surfaces.
- Define stream initiation thresholds and convert raster flow paths into vector networks.
- Delineate contributing watershed boundaries using snapped pour points.
- Interpolate continuous precipitation surfaces from discrete gauge points using Inverse Distance Weighting (IDW).
- Identify the physical limitations of bare-earth hydrologic routing in urban environments.

Datasets Provided

- Lab06_NED_10m_Ellicott.tif (Raster): High-resolution bare-earth DEM (in the lab05 folder)
- Patapsco_River_Streams.shp (Polyline): Reference stream network.
- Lab06_EllicottCity_Precip.csv (Table): Precipitation totals (in mm) from regional weather stations for the July 30, 2016 and May 27, 2018 events.
- Historic_District_Culvert.shp (Point): The primary inlet where the Tiber Branch enters the underground Maryland Avenue culvert.
- Lab06_NLCD_Ellicott.tif (raster): National Land Cover Database for the Ellicott City area. The pixel values are codes that are described here: https://www.mrlc.gov/data/legends/national-land-cover-database-class-legend-and-description
- Lab06_EllicottCity_USGS_gages.csv: USGS gage locations with peak flow discharge during the July 30, 2016 and May 27, 2018 floods.

Part A: Hydrologic Conditioning and Flow Routing

Bare-earth DEMs contain microscopic sinks and pits (both real and artifact) that trap routing algorithms. This is particularly true for DEMs in arid regions or on other planets (e.g., Mars) where erosion has disrupted the hydrologic flow paths. You therefore must condition the DEM to enforce continuous downhill flow.

1. Project Setup

- Create your lab06_lastname directory. Open a new ArcGIS Pro project.
- Set the map CRS to NAD 1983 StatePlane Maryland Meters.
- Add the data. The tables (gage data and precipitation) need to be added using their latitude and longitude.

2. Fill Sinks

- Execute the **Fill** tool (Spatial Analyst > Hydrology).
- Input: the DEM
- Output: {DEM}_Fill

3. Flow Direction

The D8 algorithm evaluates the 8 cells surrounding a central pixel and assigns a value corresponding to the steepest path of descent.

- Execute the **Flow Direction** tool.
- Input: The filled DEM
- Output: {DEM}_Fill_FlowDir ← Naming your geoprocessing files like this (_Fill_FlowDir) is very helpful for remembering a file's history
- Flow Direction Type: **D8**

4. Flow Accumulation

This tool utilizes the Flow Direction raster to count the number of upstream cells draining into any given cell, establishing the dendritic drainage pattern.

- Execute the **Flow Accumulation** tool.
- Input: the flow direction DEM
- Output: {DEM}_Fill_FlowDir_FlowAcc
- Note: Apply a Standard Deviation or Histogram Equalize stretch in the Symbology pane to make the high-accumulation flow paths visible against the zero-accumulation ridges.

Part B: Stream Delineation and Comparison

You can use a cutoff threshold to identify the stream network.

5. Define the Stream Network

This will create a binary file, where the raster values are either 1 (for stream channels) or Null (for other pixels)

- Execute the **Con** (Conditional) tool (Spatial Analyst > Math > Logical).
- The input is your flow accumulation raster
- Expression: Value > 10000 (This dictates that a stream begins only when 10,000 square meters of upslope area converge).
- Input true raster: 1
- Output: {DEM}_Fill_FlowDir_FlowAcc_1000Con
- Try running the tool a few times with different cutoffs, naming them:
    - {DEM}_Fill_FlowDir_FlowAcc_100Con
    - {DEM}_Fill_FlowDir_FlowAcc_10000Con, etc.

6. Vectorize the Network

- Execute the **Stream to Feature** tool.

- Input stream raster: your conditional stream raster
- Input flow direction: the flow direction raster
- Output: {DEM}_Fill_FlowDir_FlowAcc_1000Con_Stream

7. Urban Routing Artifacts

- Overlay your derived streams vector with the provided Patapsco_River_Streams reference layer.
- Examine the historic district on Main Street. Note where the mathematical bare-earth flow paths diverge from the mapped reference streams. Why might your derived streams be different from the USGS-mapped streams?

Part C: Watershed Delineation

Now we quantify how much rain contributed to each stream, and explore how land use may have affected runoff. To do this we need the contributing watersheds for each stream.

8. Snap the Pour Point

A pour point must sit exactly on a high flow-accumulation pixel. If it is off by even one meter, the tool will delineate a microscopic watershed for the adjacent hillslope.

- Execute the **Snap Pour Point** tool.
- Input point data: the USGS stream gages
- Snap distance: Pick a value that
- Output: Name it something easy to identify, like USGS_gages_snapped

9. Delineate the Basin

- Execute the **Watershed** tool.
- Output: {DEM}_Fill_FlowDir_Watershed
- Use the **Raster to Polygon** tool to convert this output into a vector boundary. Name it {DEM}_Fill_FlowDir_Watershed_Poly.

Part D: Precipitation Interpolation

Precipitation data is recorded at discrete gauges. In order to quantify the amount of rainfall that fell in each of your watersheds, you need to interpolate these point data into a spatially continuous raster.

10. Inverse Distance Weighting (IDW)

IDW assumes that things that are close to one another are more alike than those that are farther apart.

- Execute the **IDW** tool (Spatial Analyst > Interpolation).
- Input point features: Your projected precipitation gauge points.
- Z value field: Precip_mm.
- Output raster: Precip_IDW
- Leave the power and search radius parameters at their default values.

Part E: Hydrologic Volumetric Analysis

You now have the exact boundary of the three watersheds that drain into Ellicott City and a continuous raster of the rainfall depth. You can calculate the total volume of water deposited into this specific catchment during the storm.

11. Isolate Precipitation to the Watershed

- Use the **Zonal Statistics as Table** tool to calculate the Mean precipitation value (in inches) from your precipitation raster specifically within the boundaries of your watershed polygons.

12. Volumetric Calculation

- Join the zonal statistics data back into your watershed polygons
- Use calculate geometry and field calculator to calculate the volumetric precipitation for each watershed (when running the calculation, note the units)

Part E: Land Use

The last step is to examine the landcover within each

13. Land Cover per Watershed

- Use the Tabulate Area tool to get the area of each land cover type within each watershed
- This gives you the area (typically in square meters) of each land cover type (if your values look odd, check the CRS)
- Calculate the percentage of (1) Developed open space, (2) developed low/medium/high, and (3) forest for each of the watersheds.

Here are the National Land Cover Database codes that are in this area (for more detail see https://www.mrlc.gov/data/legends/national-land-cover-database-class-legend-and-description)

NLCD code	Description
21	Developed, open space
22	Developed, low density
23	Developed, medium density
24	developed, high density
31	Barren land (rock/sand/clay)
41	Deciduous forest
42	Evergreen forest
43	Mixed forest
52	Shrub/scrub
71	Grassland/herbaceous
81	Pasture/hay

14. Final Documentation

Address the following:

- Describe the discrepancy between your derived stream vector and the reference streams in the area. Explain the physical reason why a flow routing algorithm utilizing a bare-earth DEM fails in heavily channelized urban environments.

- You utilized IDW to map the precipitation. Explain one geometric weakness of interpolating storm cells using a small number of scattered point gauges.
- Compare the volume of precipitation and land use for each watershed with the peak streamflow as measured by the USGS gages. What patterns, if any, do you see?