GIS in Water Resources, Synopsis of Digital Elevation Model Based Watershed and Stream Network Delineation

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Watershed delineation, involving the extraction of hydrologic information from digital elevation models (DEMs) is one of the most fundamental concepts covered in this course. The advent of DEMs has resulted in the evolution of procedures to automatically map or derive channel networks and watersheds from DEMs. In this class you will learn how to do this using methods that effectively enrich the information content of a digital elevation model from simply a grid of elevation values into a data structure that represents the terrain flow field and supports quantification of contributing area and a host of other derived quantities useful for hydrologic analysis.

Learning objectives

To be able to delineate watersheds as basic hydrologic model elements from a Digital Elevation Model (DEM) using Geographic Information Systems tools and to use this information in Hydrologic Analyses

- Explain the basic concepts involved in the terrain flow information model
- Identify and fill sinks in a small digital elevation model
- Calculate hydrologic slope in the direction of steepest descent and the eight direction pour point model flow direction
- Calculate hydrologic slope and flow direction using the D∞ multiple flow direction method
- Calculate flow accumulation as the number of grid cells draining into a grid cell
- Identify a stream network raster based on grid cells exceeding a flow accumulation threshold
- Describe the sequence of steps involved in mapping stream networks, catchments and watersheds.
- Calculate specific catchment area (contributing area per unit contour width)
- Calculate topographic wetness index defined as ln(specific catchment area / slope)

Reading

- At https://pro.arcgis.com/en/pro-app/tool-reference/spatial-analyst/an-overview-of-the-hydrology-tools.htm start from "An overview of the Hydrology tools" and read to the end of Hydrologic analysis sample applications in the Hydrology toolset concepts section.
- TauDEM software documentation http://hydrology.usu.edu/taudem/taudem5/documentation.html

Optional extra reading if you are curious

- Tarboton, D. G., R. L. Bras and I. Rodriguez-Iturbe, (1991), "On the Extraction of Channel Networks from Digital Elevation Data," Hydrologic Processes, 5(1): 81-100. http://hydrology.usu.edu/dtarb/hp91.pdf
- Tarboton, D. G., (1997), "A New Method for the Determination of Flow Directions and Contributing Areas in Grid Digital Elevation Models," Water Resources Research, 33(2): 309-319. http://hydrology.usu.edu/dtarb/96wr03137.pdf

- Tarboton, D. G. and D. P. Ames, (2001), "Advances in the mapping of flow networks from digital elevation data," <u>World Water and Environmental Resources Congress</u>, Orlando, Florida, May 20-24, ASCE, http://dx.doi.org/10.1061/40569(2001)166. http://hydrology.usu.edu/dtarb/asce2001.pdf
- Tesfa, T. K., D. G. Tarboton, D. W. Watson, K. A. T. Schreuders, M. E. Baker and R. M. Wallace, (2011), "Extraction of hydrological proximity measures from DEMs using parallel processing," Environmental Modelling & Software, 26(12): 1696-1709, http://dx.doi.org/10.1016/j.envsoft.2011.07.018. http://hydrology.usu.edu/dtarb/Tesfa_EMS2011.pdf.

Synopsis

Sinks (or pits) are single grid cells or zones of grid cells in a DEM completely surrounded by higher elevation grid cells. As such they do not drain; and in hydrologic terrain analysis trap flow and cause holes in delineated watersheds. At scales of 10 m or greater these closed depressions are rare in natural earth topography, being restricted to a few special geomorphic environments (e.g. glaciated or karst landscapes). However pits occur frequently in DEMs due to data errors and sampling effects (e.g. a narrow channel may pass between grid points). It is standard practice to remove sinks prior to hydrologic terrain analysis and the standard method for doing this is to fill the sinks, raising their elevation to the point at which water would just overflow from the sink. The ArcGIS fill function does this and the result is referred to as a *hydrologically conditioned* DEM. Other methods for pit removal that "carve" flow paths, lowering terrain blocking drainage, or adjust elevations either upwards or downwards to minimize the alteration of the original DEM to obtain a hydrologically conditioned DEM have been developed, but there are not easy to use functions for these in ArcGIS.

With sinks filled the terrain flow field is numerically represented by a *flow direction grid* that encodes a set of pointers indicating the direction of steepest descent from each grid cell to one of its eight neighbors. Slope in the direction of steepest descent is a byproduct of this calculation, this procedure being referred to as the D8 method. The flow direction grid effectively defines *a grid network* that links grid cells to their downstream neighbors.

The *flow accumulation* function operates on a flow direction grid and counts (accumulates) the total number of grid cells draining into each grid cell. The result is *a flow accumulation* grid (also sometimes called contributing area grid) with high values where large quantities of flow accumulate, as in valleys or streams, and small values on hilltops and ridges.

The simplest procedure for mapping streams from a DEM is to define channels as grid cells exceeding a flow accumulation threshold. There is a question as to what is the correct threshold to use, or whether it should be the same everywhere. Much of my research has focused on these questions, developing objective methods to select the channel definition threshold and using curvature related quantities as weights in the flow accumulation to map channels with a drainage density that adapts to topographic variability. This functionality is part of the TauDEM software available from http://hydrology.usu.edu/taudem. TauDEM includes an ArcGIS toolbox written in python that serves as an interface to the functions which are C++ executable programs.

Once streams are defined a stream segmentation function calculates unique stream segments that are then the basis for delineating catchments that divide the domain into areas draining to one and only one stream segment. Subwatersheds draining to designated outlets or monitoring points can also be calculated using the flow direction grid. A last step in the terrain processing is often to convert the raster stream and catchment representations to vector shapefiles or feature classes, polylines for the stream network and polygons for catchments. The relational database associations between catchments, the stream segments that they drain to and the downstream and upstream linkages in the stream network are important for hydrologic modeling and support network analysis that enables the tracing of flow through large river networks constructed in this way.

Beyond watershed and stream network delineation hydrologic terrain analysis supports the calculation of quantities such as specific catchment area used in the TOPMODEL topographic wetness index, and other terrain proximity functions such as distance to stream and distance to the ridge. A useful function among these is the vertical distance to stream that becomes height above nearest drainage, or HAND, defining a digital elevation model relative to the streams. This has application in flood inundation mapping.