Enhanced Flow Path Methods Overview

David Saavedra, July 2018

Introduction

The Conservation Innovation Center's (CIC) Enhanced Flow Path datasets (EFP) are a unique combination of concentrated flow paths derived from elevation data, channel width estimates predicted using USGS regional curves, and high-resolution land cover data produced by the CIC. The purpose of this document is to provide a detailed overview of the geospatial steps involved in producing an EFP dataset.

Gathering Data

The first component in the production of EFP datasets is the assembly of elevation products. The primary elevation product used in the workflow is a digital elevation model (DEM). While any DEM can technically be used, better results can be achieved by using DEMs derived from high-quality LiDAR data. These DEMs are typically of higher resolution and contain more detail than DEMs derived from LiDAR of poorer quality or those created using elevation inputs other than LiDAR.

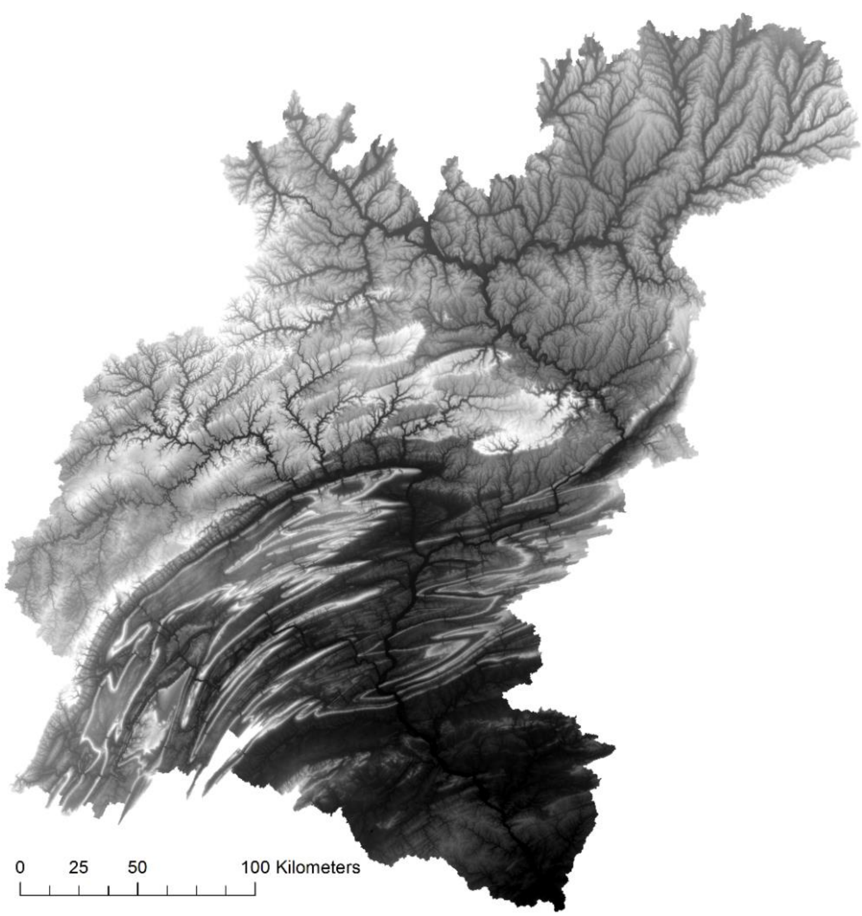

Figure 1: 1-meter digital elevation model (DEM) of the Susquehanna River Watershed used in one of the CIC's EFP datasets.

DEMs covering large geographies, like the one shown in Figure 1, often have exceedingly large file sizes, making further geoprocessing difficult or impossible. To make these datasets more manageable, HUC10 or HUC12 boundaries are typically used to divide the DEM into sub watersheds. Though there can be numerous HUC watersheds in a geography (the Susquehanna basin comprises nearly 200 HUC10 watersheds), their smaller size is more efficient for geoprocessing and they can be managed in an orderly database using the 10- or 12-digit HUC code as a unique identifier. The geoprocessing steps described in the following section are performed iteratively for each HUC watershed in the geography of interest.

Processing Data

In a DEM, cells that are of lower elevation than surrounding cells are referred to as pits or depressions. In most cases, these pits are either artifacts of the DEM creation procedure (i.e. interpolation errors), or they are caused by features on the landscape such as bridges that are of higher elevation than the stream valleys they cross (Figure 2). While water can flow freely under bridges in the real world, when represented in a DEM the bridges act much like dams, creating a depression on the upstream side and interrupting hydrologic connectivity. To address pits and depressions in a DEM, two pre-processing steps are performed. These pre-processing steps, called “breaching” and “pit-filling”, are collectively referred to as *hydro-conditioning*. The breaching step, performed first, identifies depressions in the DEM and attempts to drain them by lowering the elevation of pixels along a least-cost path from the depression to a nearby area of lower elevation so that flow can be routed through it (Lindsay, 2016). This analysis is constrained by a search radius and does not resolve all depressions in a DEM. To address remaining depressions and produce a hydro-conditioned DEM, a pit-filling procedure is performed on the breached DEM. This process raises the elevation of cells within depressions so that flow can be routed over the depression.

Figure 2: Bridges and roads crossing streams cause depressions in DEMs. These can be resolved by breaching or filling. Breaching lowers the elevataion of pixels along a least-cost path from the depression, allowing flow to be routed through an obstruction (left). Filling raises the elevation of pixels in a depression until flow can be routed over the obstruction (right).

With the hydro-conditioned DEM, a continuous flow direction surface can be generated. This is done by assigning a code to every pixel that routes flow to one of its eight surrounding neighbors based on the direction of steepest descent (O'Callaghan and Mark, 1984). The resulting grid implicitly connects every pixel and flow can be traced upslope or downslope from any pixel in the landscape.

The flow direction grid is then used to accumulate flow in the downslope direction, resulting in a flow accumulation grid where the value of each pixel represents the number of upslope pixels flowing to it. The number of upslope pixels contributing flow to any given cell can be multiplied by the cell area (e.g. 1 square meter for a 1-m resolution DEM) to calculate the amount of land area draining to the cell. This is referred to as the contributing area or drainage area.

Flow accumulation grids can be used to delineate flow networks by applying a contributing area threshold. Cells in the flow accumulation grid with a contributing area greater than the threshold will be flagged for inclusion in the flow network, while cells with contributing area less than the threshold are set to null (Band, 1986; Maidment, 2002). The value that is chosen for the threshold will have a significant impact on the network that is delineated – a smaller contributing area threshold will produce a flow network with a much higher drainage density (i.e. more flow lines per unit area on the landscape), while a larger threshold will produce a more conservative flow network (Figure 3). Care should be taken when deciding upon a threshold value and the flow network's intended purpose should be taken into consideration. Small thresholds are useful for illustrating overland flow that may not necessarily be concentrated enough for channelization to occur, and larger contributing area thresholds can be applied to delineate ephemeral/perennial streams and other areas of significant concentrated flow. The CIC typically applies a 60-acre contributing area threshold when producing EFP datasets.

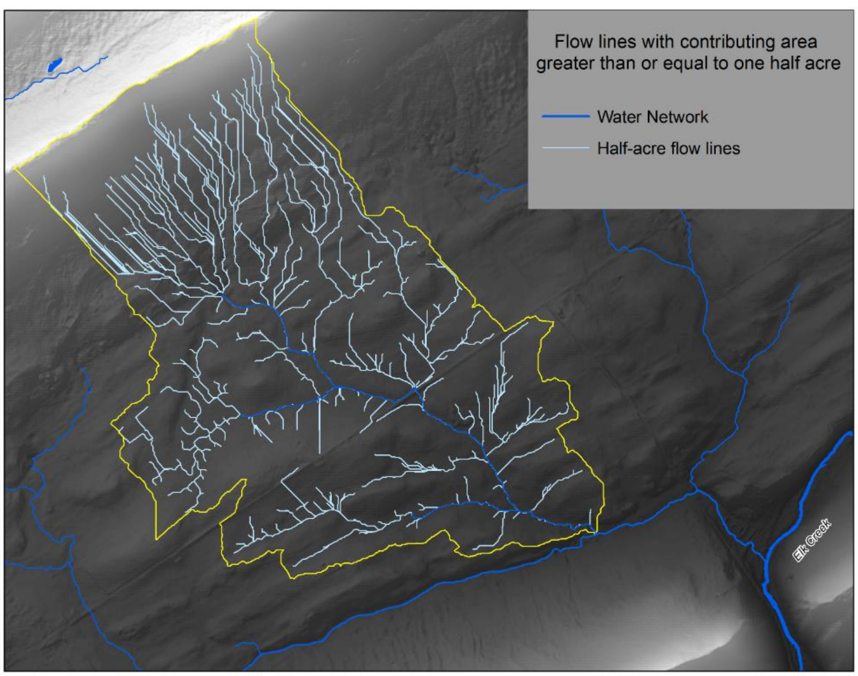

Figure 3: Two different flow networks illustrating the impact of contributing area thresholds. A half-acre threshold was applied to delineate the network shown in light blue and a 60-acre threshold was applied to delineate the network in dark blue. Note the smaller threshold produces a much denser flow network.

Once a flow network has been delineated using a contributing area threshold, it is then discretized into *stream segments*. A stream segment, also referred to as a stream link or stream reach, is the segment of a flow network from headwaters to a junction, from junction to junction, or from junction to outlet. Each segment is assigned a unique identifier so it can be manipulated independently in subsequent processing steps. This manipulation includes a summarization of the contributing area to each segment and the application of a regional curve equation to estimate channel width based on drainage area. Regional curves, published by the USGS, are empirical equations derived from field measurements that relate channel geometry (bankfull width, depth, and area) and discharge to contributing area. The USGS publishes many regional curves for many different geographies, making it possible to apply equations developed specifically for a given project area. After a qualitative evaluation of several regional curves developed for many of the physiographic provinces in the Chesapeake Bay watershed, the CIC found that an equation developed for the Coastal Plain of Maryland and Virginia (Krstolic and Chaplin, 2007) worked quite well across the watershed and typically applies this equation for projects in the Chesapeake region.

With drainage area and bankfull channel width estimated for every stream segment in the flow network, the stream segments are then widened according to the channel width estimate. This transforms the network from a one-dimensional linear network to a two-dimensional polygonal network (Figure 4). Having stream width estimates spatially represented makes the EFP dataset a valuable tool for conservation and restoration planning as the interface between edge-of-stream and land – where many conservation and restoration practices are implemented – is more precisely mapped.

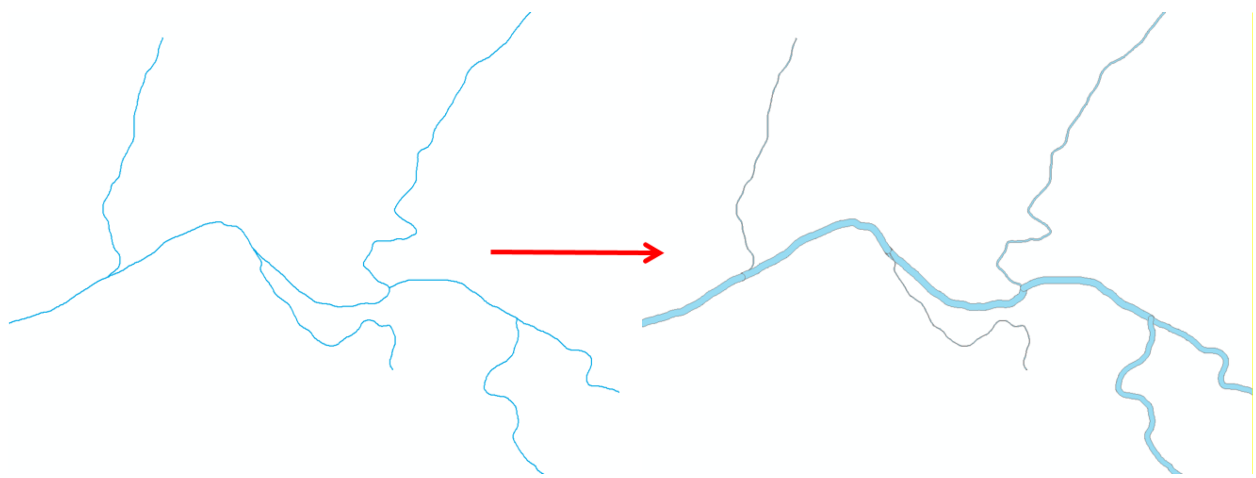

Figure 4: One-dimensional linear network (left) is widened to create a two-dimensional polygonal network (right) where stream segments with larger drainage areas have greater widths.

To further enhance the edge-of-stream boundaries and make the widened flow network integrate more seamlessly with other data from the CIC such as the High-Resolution Land Cover dataset (HRLC; Conservation Innovation Center, 2016), the widened network is supplemented with the "Water" class from the HRLC. Pixels from the HRLC that are identified as "Water" are isolated and combined with the widened flow network. The resulting raster grid is a powerful planning tool that is complementary to the HRLC. The widened flow network supplements the HRLC where water is discontinuous or hidden by tree canopy, and the HRLC supplements the flow network where multiple braided channels exist, or where the width of large rivers is not estimated correctly by the regional curves (Figure 5).

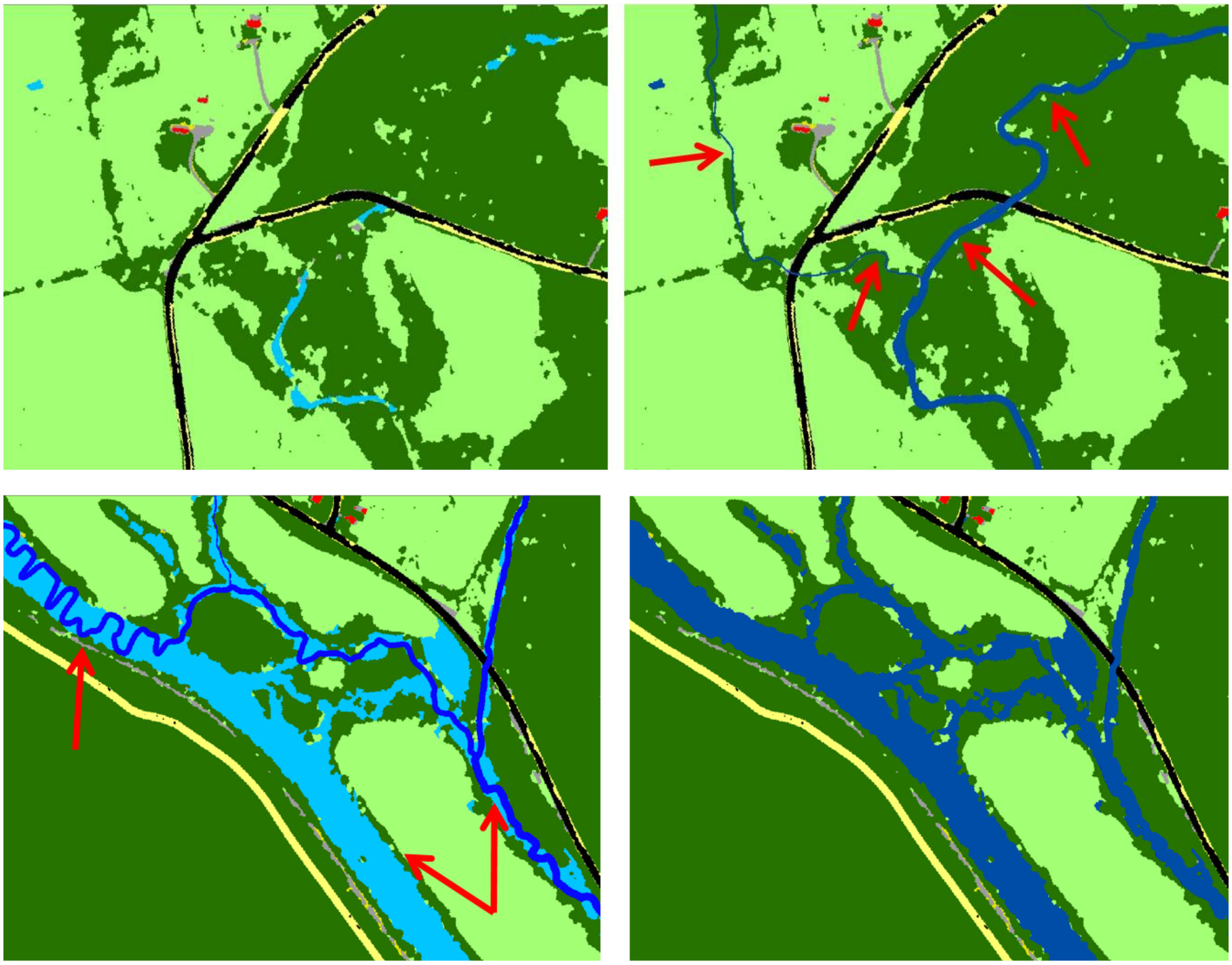

Figure 5: HRLC water (light blue) is supplemented by the widened flow network (dark blue) where tree canopy obscures a stream (top row). HRLC water supplements the widened flow network where multiple channels exist and where channel width is underestimated in large river (bottom row).

Limitations

While the EFP datasets are powerful and novel conservation and restoration planning tools, they do have limitations like any other geospatial dataset. Because the workflow to produce EFPs relies heavily on elevation data, the quality of elevation data has a significant impact on the quality of the resulting EFP. Best results are obtained when high-quality LiDAR-derived DEMs are used as input. Quality LiDAR exists for much of the area where the CIC has applied these methods and more is being collected at a rapid pace. A second limitation is in the use of a constant contributing area threshold to delineate the flow network. While this method is well-documented in scientific and academic literature and is readily practicable in a GIS environment, it is vulnerable to errors of commission and omission, particularly in headwater areas. Consideration of the intended purpose of the EFP should be taken when deciding on a threshold value. One other limitation stems from the use of empirically-derived regional curve equations to estimate channel width. By their very nature, these equations contain some degree of error, especially when applied over large geographies where many factors can affect channel width. However, these equations typically perform well for most smaller channels, and errors in the width of larger channels are usually alleviated by the incorporation of HRLC water into the dataset.

Summary

The CIC developed a novel method for creating flow path datasets incorporating terrain data, channel width estimates, and high-resolution land cover. Terrain data are analyzed and flow direction and flow accumulation are calculated. USGS estimates of channel width are applied to each individual segment of the network and the widened flow network is then combined with high-resolution land cover data. The resulting datasets are powerful conservation and restoration planning tools that are already being used by practitioners in several different geographies. These datasets precisely map the interface where land and water meet and enable precision conservation practices to be implemented in a targeted and effective manner. The methods to produce the datasets described in this report are readily portable to any geography with quality elevation and land cover data.

References

Band, L.E. 1986. Topographic partition of watersheds with digital elevation models. Water Resource Research 22: 15–24.

Conservation Innovation Center, 2016. Chesapeake Bay High-Resolution Land Cover Project. http://chesapeakeconservancy.org/conservation-innovation-center/high-resolution-data/land-cover-data-project/

Krstolic, J.L., and Chaplin, J.J., 2007, Bankfull regional curves for streams in the non-urban, non-tidal Coastal Plain Physiographic Province, Virginia and Maryland: U.S. Geological Survey Scientific Investigations Report 2007–5162, 48p.

Lindsay, J.B. (2016). Efficient hybrid breaching ‐ filling sink removal methods for flow path enforcement in digital elevation models. Hydrological Processes, 30(6), 846-857.

Maidment, D.R. (2002). *Arc Hydro: GIS for water resources* (Vol. 1). ESRI, Inc.

O'Callaghan, J., and Mark, D. 1984. The extraction of drainage networks from digital elevation models. Computer Vision, Graphics, and Image Processing 28: 328–344.