Exploring Methods of Floodplain Delineation

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Purpose

This page outlines and compares efforts used to identify a hydrologic, geomorphic, and geospatially sound method to delineate floodplain extent. The goal of this effort is to map floodplains and other types of corridors for local studies, with a strong focus on tools/methods that can be expanded to map the entire Nation. Smith Creek near New Market, Virginia is used as a test basin for each method. Each method is outlined below followed by a comparison of the results.

Methods explored include:

- USGS Stream Channel and Floodplain Metric Toolbox (Beta Version 1.3) by Lamont et al.
- An adaptation of the methods outlined in Geospatial Assessment of Ecological Functions and Flood-Related Risks on Floodplains along Major Rivers in the Puget Sound Basin, Washington by Christopher P. Konrad
- USFS Riparian Buffer Delineation Tool by Sinan Abood

USGS Stream Channel and Floodplain Metric Toolbox (Beta Version 1.3)

Overview

This tool was created by the Natural Resource Analysis Center (NRAC) at West Virginia University (WVU) to demonstrate the feasibility of mapping fluvial geomorphic features from multi-resolution bare-earth elevation data. A Python toolbox for ArcGIS was built to calculate key metrics describing channel and floodplain geometry based on published works such as GeoNet (Passalacqua, 2012), the Riparian Topography Toolbox (Dilts and Yang, 2010), and the River Bathymetry Toolkit (McKean, et al, 2009), among others. This toolkit provides the ability to calculate specific channel and floodplain geometry metrics on a watershed scale. The tool works using TauDEM, a free terrain analysis software package which can be obtained here. TauDEM is open source and has the ability to run on regional datasets.

Processing Steps

1. The tool utilizes a bare-earth Digital Elevation Model (DEM). For Smith Creek, a 1/9 arc second (~3 meters) DEM was downloaded from the National Map. (Figure 1)
To target the sample basin, the DEMs which overlay the basin were merged together using the Mosaic to Raster tool, clipped and projected in ArcMap using 4 HUC12 watersheds within the HUC10 watershed for Smith Creek.

3. The raster is inspected for holes and filled using raster calculator in ArcMap (Expression: Con(IsNull[Raster], FocalStatistics([Raster], NbrCircle(10, "CELL"), "MEAN"))).

4. The DEM is breached to be sure that the delineated streams crossing culverts and under bridges by using the Breach Depressions tool in an open source program called Whitebox GAT.

5. Pit Remove, Flow Directions, and Contributing area functions are performed using TauDEM creating four separate rasters including a pit filled DEM, flow direction, degree slope and flow accumulation or contributing area.

6. The output rasters from step 5 are run through the TauDEM Post-Processing tool to format them for input into the Bank Detection and Floodplain Analysis tool.

7. The final step is to run the rasters through the Bank Detection and Floodplain Analysis tool. This tool performs several steps. Stream channel cross sections are created and slope analysis is performed at each cross section in an effort to determine stream bank locations. If the slope break threshold is not met, often due to lakes or reservoirs, no bank points are created for the associated cross section. The elevation of the resulting stream channel bank points are used to create a floodplain extent grid based on the "Height Above River" methodology (Dilts and Yang, 2010). This method uses the Spatial Analyst extension’s kernel density function to calculate a distance-weighted average of river elevations, where cells in the river that were nearer to the upland grid cells receive a greater weight than cells located farther away. The weighted average river elevation was then subtracted from the elevation of individual grid cells to derive height above river for each location. Floodplain metrics are calculated using floodplain cross sections, which intersect the stream channel at the sample point as the channel cross sections.

The user is able to alter parameters in the analysis including the following related to floodplain detection (Figure 2):

a. spacing between cross sections (m): interval between channel and valley cross sections along the reach segment. The default (9 meters) was used for this analysis.

b. channel cross section linear fit (m): straight line segment of stream reach used to create cross sections. Cross sections are perpendicular to this line, passing through its midpoint. The sensitivity to sinuosity can be controlled with this parameter. The default (30 meters) was used for this analysis.

c. point spacing along cross sections (m): spacing of points along each cross section used to extract elevation values from the input DEM grid. The resolution of the DEM is recommended. 3 meters was used for this analysis.

d. Floodplain parameter: Search radius (m): search radius determines the degree of smoothing used by the kernel density functions as well as the maximum distance from the river for the output raster which are parts of the DEM de-trending algorithm, the default (200 meters) was used for this analysis.

e. Floodplain parameter: Height threshold (m): a “flood height” threshold used for calculating inundation areas or floodplain extents. The default (1 meter) was used for this analysis.

8. The tool creates a floodplain raster along with three other GIS layers including: bank points shapefile, channel cross section shapefile, and a valley cross section shapefile. The floodplain extent raster follows the method in the Riparian Topography Toolbox (Dilts and Yang, 2010) where weighted average of the stream bank elevation is compared to the surrounding elevation values. The weighted averaging is performed using a kernel density approach with the calculated bank location points. A model of flood inundation area or floodplain extent from a constant threshold value; the larger the constant, the greater the inundation area.

Output
This toolbox was designed for regional use, specifically in the Chesapeake Bay watershed. The processing time for DEM acquisition, pre-processing, post-processing and analysis of a HUC 10 watershed is approximately 90 minutes using mostly default parameter settings. Processing and run-time statistics would be subject to change with higher or lower resolution DEMs and larger or smaller watersheds.

The output raster can be seen in Figure 3.

USFS Riparian Buffer Delineation Tool

Overview

This tool was created by Dr. Sinan Abood from the U.S. Forest Service in an effort to create a more robust, hydrologically, and geomorphologically significant approach to delineating riparian ecotones. This approach was designed to enhance the fixed width buffer that has commonly been used for historical ecological riparian analysis. Fixed width buffers have been proven to be inadequate, as they do not emulate natural riparian corridors since they have no functional relationship to the naturally varying watercourse. In Skally and Sagor (2001), natural riparian ecotone boundaries were proven to be an average 2.5 time farther from the stream than what was mapped using a fixed width buffer. This tool hydrologically defines the riparian ecotone area by incorporating calculated 50 year flood heights with a DEM and the National Hydrography Data set using an ArcGIS toolbox.

Processing Steps

1. The tool utilizes a Digital Elevation Model (DEM). For Smith Creek, a 1/3 arc second (~10 meters) DEM was downloaded from the National Map.
2. The tool creates floodplains based on NHDPlus Version 2 flowlines and waterbodies. Unwanted stream features such as pipelines, ditches etc. are removed from the flowlines, and unwanted lake features such as ice caps, playas, etc. from Hi-Res waterbodies.
3. Streams and lakes are clipped to study area.
4. 50-year flood height values are calculated for each stream order using Mason (2007). This flood recurrence was selected because in most cases the 50-year flood height intersects the first terrace or other upward sloping surface and supports the same microclimate and geomorphology as the stream channel. This excel-based calculation utilizes NWIS Annual Statistics and Field Measurements for the USGS gage within the watershed to calculate flood heights by stream order for the watershed. The calculated 50 year flood height values are plotted against stream order, and a second order polynomial equation is fit to the values to estimate flood values for ungauged streams. Estimated values are joined to NHDPlus Version 2 flowlines based on stream order.
5. Watershed boundary, flowlines, waterbodies, and the DEM are imported into the RBDM tool (seen in Figure 2). The tool also offers additional options to include and expand upon the analysis for ecological purposes including slope threshold, wetlands, SSURGO, and land cover data. The tool creates a riparian area extent shapefile.

Output

This tool was designed by the USFS to create a national context inventory of riparian areas and their condition within national forests and rangelands, but can be used for simple hydrologic estimation. The output of the tool is shown in Figure 4.
An adaption of the methods outlined in Geospatial Assessment of Ecological Functions and Flood-related Risks on Floodplains along Major Rivers in the Puget Sound Basin, Washington

**Tool Overview**

This is an adaptation of the flood risk assessment created by Christopher Konrad in the Puget Sound Basin. It extracts floodplain delineation techniques used in the assessment of flood risk and hazard in the Puget Sound Basin in Washington. The original methods address five ecological functions, five components of flood-related risks at two spatial resolutions—fine and coarse. The fine-resolution assessment compiled spatial attributes of floodplains from existing, publicly available sources and integrated the attributes into 10-meter rasters for each function, hazard, or exposure. The raster values generally represent different types of floodplains with regard to each function, hazard, or exposure rather than the degree of function, hazard, or exposure. The coarse-resolution assessment tabulates attributes from the fine-resolution assessment for larger floodplain units, which are floodplains associated with 0.1 to 21-kilometer long segments of major rivers. The coarse-resolution assessment also derives indices that can be used to compare function or risk among different floodplain units and to develop normative (based on observed distributions) standards.

**Processing Steps**

1. This method utilizes some of the same data files used as input to the Riparian Buffer Delineation tool, including: 10 meter DEM, NHDPlus Hi-Res flowlines, and the 50-year flood height estimation.
2. The 50-year flood height estimations are joined to the NHD Hi-Res flowlines based on stream order. These flowlines are converted to TIFF format based on the flood height attribute.
3. The flood height raster is added to the DEM raster in Raster Calculator in order to calculate true elevation values of the stream surface (shown in Figure 1).
4. The resultant values of the stream surface elevation calculation are converted into points.
5. The stream surface elevation points are used to compute an Inverse Distance Weighting interpolation. The extent and cell size of the computation are set to be the same as the DEM. The power setting, or the exponent of distance which controls the significance of the surrounding points on the interpolated value, is set to 2. The search range is set to 75 points.
6. The difference between the DEM and the interpolated stream surface raster is calculated in Raster Calculator.
7. The difference calculation from step 6 is used in Raster Calculator within a conditional statement (shown in Figure 2). This calculation assigns a value of 1 to all values in the difference calculation raster that are less than the maximum flood height. This results in a binary raster where 1 represents the floodplain extent and 0 represents no data values.

**Output**

This tool was adapted from a regional flood risk analysis in Washington. A 50-year flood height was used for comparison purposes, but different flood heights could be tested. The output raster is shown in Figure 3.
Comparing Methods

Time

Processing time for the floodplain delineation method are based on data resolution and complexity of analysis.

For a HUC 10 watershed, the USGS Stream Channel And Floodplain Metric Toolbox (SCFMT) requires approximately 90 minutes to process. This includes the pre-processing requirements involved with preparing the DEM, the higher resolution of the DEM, and the many steps involved in delineating streamlines, identifying bank points, etc.

For a HUC 10 watershed, both the Riparian Buffer Delineation Tool (RBDT) and the adaptation of the Konrad method (KM) require approximately 30 minutes to process, for a 10 meter DEM.

Data Availability

The SCFMT requires a 3 meter resolution or finer LIDAR based DEM. The availability of such is very limited. Figures 1 and 2 show the availability of 1 meter and 1/9 arc second (~3 meter) DEMs.

Both the RBDT and KM utilize 1/3 arc second DEMs. Figure 3 shows the availability of 1/3 arc second DEMs.
Accuracy

The SCFMT delineates the floodplain based on the streamlines derived from the input DEM. This allows results in a more detailed analysis and the ability to capture smaller shifts and changes in the hydrology of the basin. However, due to the arbitrary nature of establishing an accumulation threshold used to delineate a stream network, often smaller order streams may delineate features not related to the stream, such as roads. An example of this is shown in Figure 4. The RBDT and KM both use NHDPlus Version 2 flowlines. While using already established NHDPlus Version 2 flowlines allows for a much faster processing time, it limits the accuracy of the stream hydrology, and therefore the floodplain. Figure 5 shows an example of then NHDPlus Version 2 flowlines compared to those derived from a 3 meter DEM. The NHDPlus Version 2 flowlines are smoothed, and do not capture all of the meanders and smaller order streams that may be occurring.

To delineate the floodplain, each method requires a flood height as input. For the SCFMT a default value of 1 is used unless changed by the user. This value is used for all stream orders in the watershed. While this allows for consistency and simplicity, it is arbitrary and may not reflect the actual flood heights of each basin, and of each stream order within the basin. The RBDT and the KM utilize Mason (2007) to calculate a 30 year recurrence interval using field measurements from nearby gages to detrend to the entire watershed based on stream order. While this calculation is dependent upon the availability of field data, it creates a flood height value that is more reflective of the mechanics of the watershed. However, there is a debate regarding the usefulness of a 30 year recurrence interval versus a 2 or 5 year recurrence interval.

Results

Figure 6 shows a snapshot of the results of each method on Smith Creek. The legend in the bottom right corner of the image identifies that the cyan colored polylines represent the streamlines derived from the 3 meter DEM, the darker blue represents the NHDPlus Version 2 flowlines, the purple represents the BFDT floodplain extent, the green represents the KM floodplain extent, and the red represents the RBDT floodplain extent.

While determining the accuracy of the results to the natural floodplain is difficult due to the subjective nature of field floodplain surveys, comparing the results of each method to each other, and using orthoimagery can help determine the precision.

The KM appears to result in more areas outside of the obvious floodplain being
delineated, such as patches of forest and farmland.

The SCFMT