Mapping stream and floodplain geomorphic characteristics with the Floodplain and Channel Evaluation Tool (FACET) in the Mid-Atlantic Region, United States

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Abstract—**Quantifying channel and floodplain geomorphic characteristics is essential for understanding and modeling sediment and nutrient dynamics in fluvial systems. The increased availability of high-resolution elevation data from light detection and ranging (lidar) has helped improve methods for extracting these metrics at a greater accuracy across regional scales. The Floodplain and Channel Evaluation Tool (FACET) was developed as an open source tool to calculate a suite of geomorphic metrics describing channel and floodplain geometry from high-resolution digital elevation models (DEMs), providing estimates of channel width, bank height, cross-sectional area, and floodplain extent. Field data from sites in the Chesapeake Bay and Delaware River watersheds were used to calibrate and validate FACET within five physiographic provinces in the Mid-Atlantic region of the United States. Stream banks were identified using either a slope-threshold method at cross sections, which are automatically generated at a user-defined interval along the delineated stream network, or by applying a curvature-threshold method for grid cells within a buffered distance from the stream network. The floodplain extent was mapped using a height above nearest drainage (HAND) grid and empirical regression models built for each physiographic province relating the HAND threshold to drainage area. Other user-defined input parameters within FACET control the sensitivity of calculations to DEM resolution, relief, and stream order, allowing for the ability to optimize FACET at multiple scales and/or regions if field survey data are available for calibration. Geomorphic metrics derived from FACET are currently being used to develop predictive models to estimate bank erosion and floodplain deposition to enhance our understanding of watershed sediment and nutrient budgets.**

I. INTRODUCTION

Sediment and nutrients in fluvial systems follow a dynamic cycle of erosion, transport, and deposition as they move through river systems [1]. Modeling the amount of sediment eroded from banks, deposited on floodplains, and exported from the system is essential for developing accurate watershed sediment and pollutant budgets for land and water resource decision making. Key parameters in these models are field-measured rates of sediment and nutrient fluxes and measurements of stream and floodplain geomorphic characteristics such as channel width, stream bank height, and floodplain width to scale field data to large stream networks. The increasing availability of high-resolution elevation datasets derived from lidar now makes it possible to obtain stream and floodplain geomorphic characteristics at finer watershed scales. The Floodplain and Channel Evaluation Tool (FACET) [2] was developed to allow for a regional-scale analysis of stream and floodplain geomorphic characteristics with minimal field data for calibration and calculation. To run FACET in the Mid-Atlantic region of the United States, a high-resolution DEM and knowledge of terrain in the area of interest to select appropriate input parameters are the only requirements needed to calculate the geomorphometry of stream banks and floodplains at the watershed scale.

II. METHODS

FACET was developed using open-source geospatial libraries in Python to calculate geomorphic metrics using lidar-derived DEMs. Field-based channel and floodplain characteristics were measured at 68 sites in the Chesapeake Bay and Delaware River

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Watersheds (Fig. 1). These data were used to calibrate the active floodplain extent and assess FACET metric accuracy.

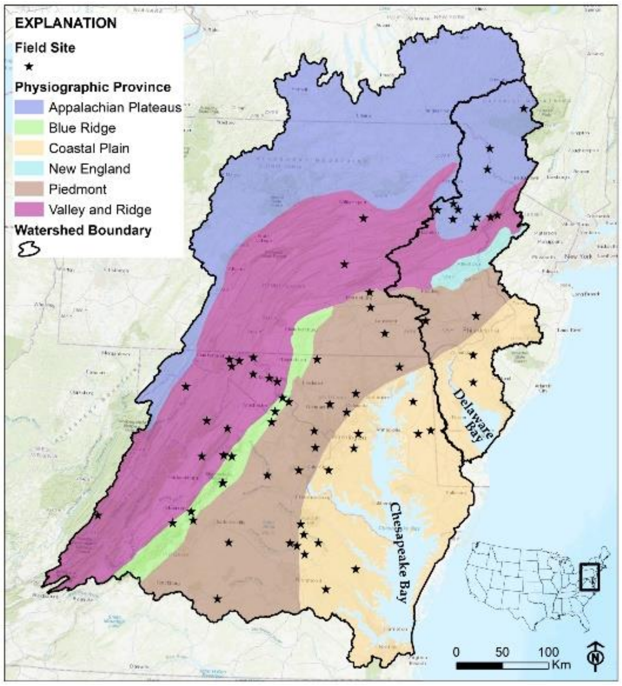

Figure 1. Location of 68 field sites spanning five physiographic provinces in the Chesapeake Bay and Delaware River Watersheds. Channel width, bank height, and floodplain width were measured at each field site. Bank erosion and floodplain deposition rates were estimated using dendrogeomorphology. Soil chemistry data collected at each site were also used to calculate sediment and nutrient fluxes.

A. FACET input data and pre-processing

Lidar-derived DEMs covering the study area varied in quality level (i.e., resolution, vertical and horizontal accuracy) and therefore were resampled to 3 meters for consistency. DEMs were hydrologically conditioned using pre-processing steps built into FACET. First, road-stream and railroad-stream intersections were identified as barriers to surface flow and breached. To ensure any additional barriers not breached in the first method were addressed, the fast breach algorithm in Whitebox Tools [3] was then applied to the DEM. D8 flow direction and contributing area were then calculated using Terrain Analysis Using Digital Elevation Models (TauDEM), version 5.3.7. [4], to delineate a stream network based on the end nodes of the U.S. Geological Survey (USGS) 1:24,000-scale High Resolution National Hydrography Dataset (NHD High Res.) [5].

B. Stream bank identification

FACET contains two separate methods to delineate stream banks [2]. The first is a slope break approach, which uses a series of cross sections placed perpendicular to the channel and spaced at user-defined intervals. Within the elevation profile of each cross section, a series of horizontal lines are spaced above the lowest point along the cross section at a user-defined vertical increment. Once the user-defined ratio between the length of a horizontal line and the next highest line is exceeded, FACET searches for a slope break that exceeds a user-defined threshold to identify the top of the bank on each side of the cross-sectional profile of the channel. Each bank point pair contains a measurement for bank height, bank angle, channel width, and channel area (Fig. 2).

The second method of bank detection is a raster-based curvature approach. FACET calculates curvature within a moving window along the stream network using two optional methods: mean curvature and wavelet-based [6]. Pixels within a buffered distance from the stream network falling within the curvature threshold are identified as banks. Mean channel widths from the curvature approach are summarized by stream segments. The user can adjust the moving window size, curvature threshold, and buffer distance.

C. Floodplain delineation

A height above nearest drainage (HAND) grid was generated using the TauDEM D-infinity vertical averaged distance downstream to identify the vertical distance between each pixel on the landscape to the location along the stream network to where it drains. HAND height thresholds corresponding to the edge of the floodplain mapped in the field were identified for 57 of the 68 field sites across five physiographic provinces: Appalachian Plateau, Blue Ridge, Coastal Plain, Piedmont, and Valley and Ridge (Table 1). The HAND threshold for each field site was related to drainage area and physiographic province in a linear regression model to predict unique HAND thresholds for unmeasured sites. Predictions were limited to drainage areas greater than 3 km^2 and less than 3000 km^2, reflecting the drainage area distribution of the field sites. HAND threshold predictions for each stream reach catchment were applied to the HAND grid to create a continuous floodplain raster for the watershed. (Fig. 2).

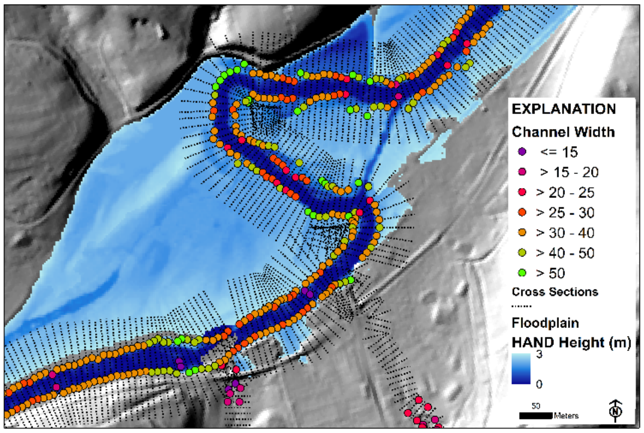

Figure 2. Example of banks derived using the slope break approach. A pair of bank points were identified for each cross section drawn perpendicular to the channel. Channel width, bank height, and other channel metrics were quantified at each cross section/bank point pair. Example also shows output of the HAND-derived floodplain along the reach.

III. Results and Conclusions

A significant relationship between HAND threshold and drainage area was identified for the Appalachian Plateau, Piedmont, and Valley and Ridge sites ($R^2 = 0.59$, $p < 0.001$). A static HAND threshold was used within the Coastal Plain (HAND = 1.65 m) and the Blue Ridge (HAND = 1.56 m) (Table 1).

Table 1. Mean and range of HAND thresholds corresponding to field-mapped active floodplain extent within each physiographic province.

Physiographic Province	Number of Field Sites	HAND Threshold Range (m)	HAND Threshold Mean (m)	Drainage Area Range (sq km)
Appalachian Plateau	9	0.2 - 1.8	1.04	52 - 285
Blue Ridge	8	0.6 - 1.9	1.56	11 - 26
Coastal Plain	14	0.6 - 3.8	1.65	33 - 2,792
Piedmont	13	0.7 - 5	2.55	20 - 1,604
Valley & Ridge	13	1 - 4.9	2.18	16 - 1,748

FACET accuracy was assessed using the root mean square error (RMSE), comparing the FACET-derived values for channel width, bank height, and floodplain width with the field-measured values of each metric along each overlapping reach (Fig. 3). FACET tended to overestimate channel width and bank height in the Blue Ridge region where the topography is more complex and the drainage area of field sites ranged from 11 to 26 km^2, indicating the ability for FACET to accurately detect banks in small mountainous headwater streams was limited. In the Coastal Plain, Piedmont, and Valley and Ridge regions where drainage areas of field sites were larger and banks were typically more defined, estimates from FACET match field values more closely. FACET tended to overestimate floodplain width in the Valley and Ridge region but did not consistently over or underestimate floodplain width in the Piedmont or Coastal Plain region. Other variables influencing FACET accuracy could be lidar quality and characteristics used to delineate floodplains in the field that are not as evident from lidar (e.g., microtopographic changes, flow-oriented debris, and shifts in vegetation type).

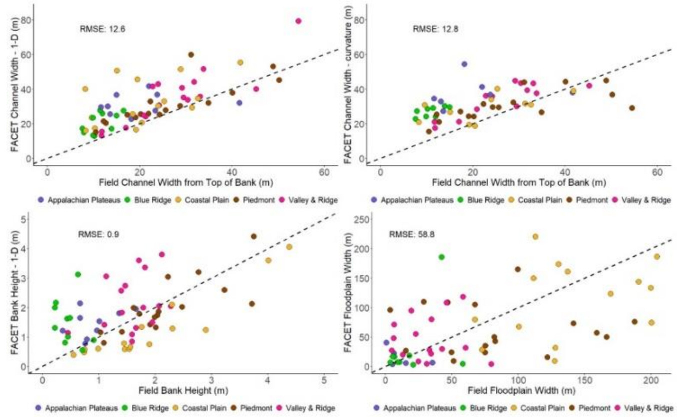

Figure 3. Plots showing the FACET versus field-derived measurements of channel width, bank height, and floodplain width for each of the 68 field sites, along with the root mean square error (RMSE) value for each comparison. Sites within each physiographic province are grouped by color.

FACET-derived geomorphic metrics are currently being used to scale up field measurements of sediment and nutrient fluxes calculated at each of the 68 field sites to predict fluxes from streambank erosion and floodplain deposition across the entire Chesapeake Bay and Delaware River Watersheds.

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