Sediment Transport Assessment Using DEMs One Decade Apart: A Case Study on Turtle Creek Watershed in Union County, PA

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Introduction

Geographic Information Systems (GIS) can use high-resolution Lidar and multispectral images collected from aircraft to provide detailed maps of various characteristics of a watershed. In tributaries to the Chesapeake Bay, including the Susquehanna River, sediment transport is of particular interest because of its impact on the Chesapeake ecosystem. Sediment may originate in tiny rills in the upland areas of a watershed, or in the main channel as bank erosion. This work focuses on mechanisms that work at a scale in between the rill and the channel network scale.

Previous work at Bucknell has concentrated on flow path modeling and using digital elevation models (DEMs) along with Land Use and Land Cover (LULC) maps to develop an index of pollution potential in concentrated runoff flow paths. Last summer (2019) a new index was developed, based on work by Moore and Wilson (1992). This work used the stream power index (representing flow rate multiplied by slope) to represent the capacity of a flow path to carry sediment. Based on the assumption that high sediment transport capacity corresponds with high sediment transport during large floods, maps showing sediment transport capacity along concentrated flow paths were developed. Data to evaluate various indices were not available in 2019 because of dry weather during the weeks available for research.

In 2020, plans were made to measure sediment deposition in upland areas, but COVID-19 restrictions made collection of these data impossible this summer. The work this summer attempted to validate various sediment transport indices by using two high resolution DEMs taken 11 years apart (in 2006 and 2017). Actual differences (presumably not numerical artifacts) between these two DEMs should represent soil erosion or deposition. Figure 1 is a topographic map of the watershed. Figure 2 is a map showing the difference in elevations between these two DEMs at a 1 m horizontal scale. Light colors represent erosion and dark colors represent deposition.

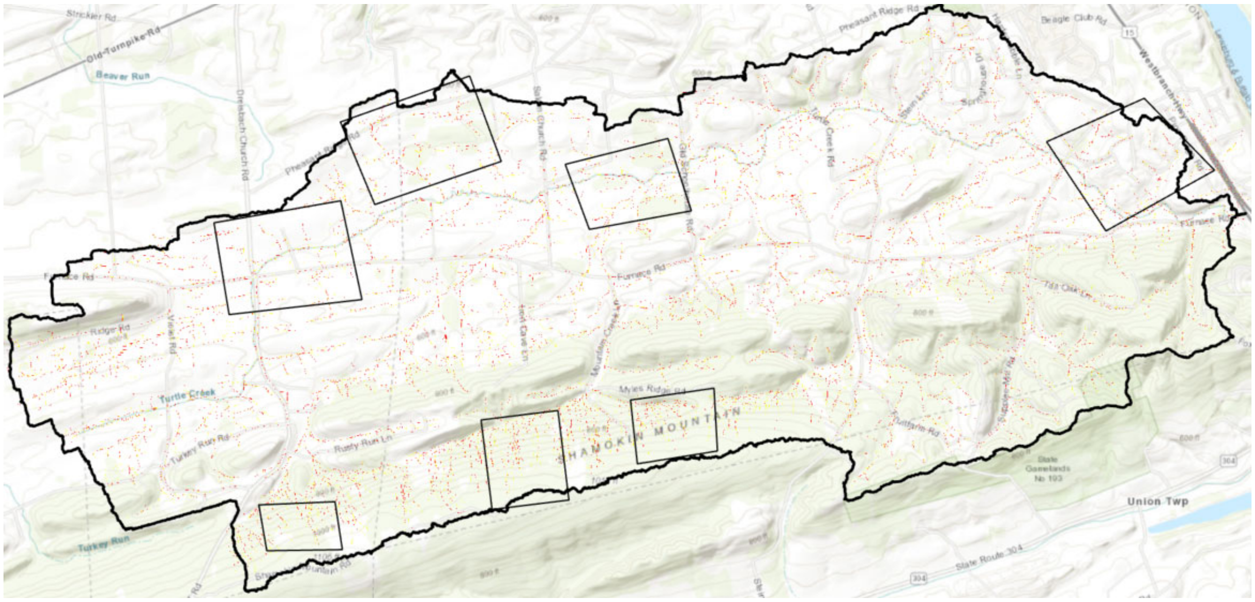

Figure 1. Map of the Turtle Creek watershed. The polygons are seven study areas used in the data analysis

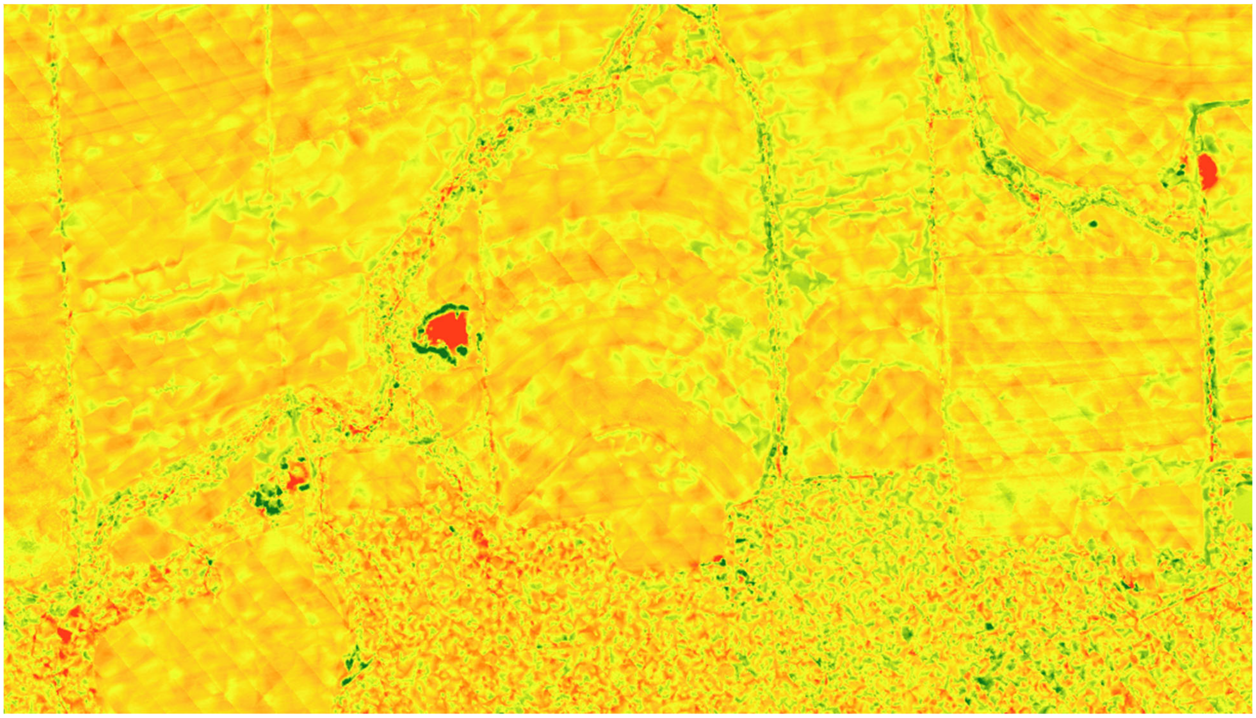

Figure 2. Close-up of map of DEM2006 – DEM2017, with red colors representing elevation loss and green representing elevation gain. Large red patches are construction sites.

The hypothesis of this research was that other indices of sediment transport should be related, pixel-by-pixel, to the elevation differences in Figure 2. Table 1 shows the indices that were used in this work:

Table I. Variable Used.

Variable	Comments
E_{dif}	Difference between 2006 and 2017 DEMs. Considered a direct measurement of elevation differences, presumably due to soil motion.
Stream power index, T	$T = [\text{Contributing area (m}^2)]^{0.6}(\text{Local ground slope})^{1.3}$ T is a sediment transport capacity [Moore and Wilson, 1992].
$\mathrm{d}T/\mathrm{d}s$	$\mathrm{d}T/\mathrm{d}s$ is the downstream gradient in T. If positive, it implies erosion; if negative, it implies deposition.
Streambank condition	Rating scales for streambank stability, evaluated using photos of the stream taken from bridges in the watershed (rating scale from West Virginia DEP, retrieved 2020).
Distance between start of flow paths	Flow paths were assumed to begin once 3000 cells (1m by 1m) contributed runoff. Positions on the map where the 2006 paths started far from where they started in 2017 were assumed to have experienced considerable soil movement. (See Figure 3)
Integrated E_{dif}	Mean E_{dif} over the contributing area at the start of a flow path. This is assumed to correspond to the cumulative soil transported to the start of the concentrated flow path.

Figure 3. Yellow (red) lines represent 2006 (2017) flow paths. Distance between the start of corresponding paths is one measure of soil displacement considered here.

Findings

While the indices were all successfully developed, mapped and graphed, there was little if any correspondence among all the indices. In particular, it was expected that T at the start of a flow path would have a close relationship with Integrated E_{dif} (Table 1), since T is transport capacity, and a large value for Integrated E_{dif} would require a high transport capacity. However, no generally-applicable relationship was discernible.

A key aspect to consider is the spatial and temporal scales appropriate to each index. The DEM, with spatial resolution (1m) might be too detailed to accurately represent soil transport processes. Therefore, various smoothing and averaging techniques were applied at various stages of data processing, but with little success. It would appear that:

1. There is a remaining mismatch in scales between the indices in Table 1 and E_{dif}, such that 10 m resolution would be more appropriate than 1 m, or
2. The vertical precision/accuracy of the DEMs from which E_{dif} was derived are inadequate for this purpose, or,
3. The DEMs were not perfectly stacked on top of each other, or
4. The data processing that ensured the DEMs did stack properly actually introduced some bias, or
5. None of the indices are applicable in this watershed.

In order to determine which of these conclusions is correct, actual measurements of sediment transport are needed.

References

West Virginia Department of Environmental Protection, Assessing Bank Erosion Potential Using Rosgen's Bank Erosion Hazard Index (BEHI), https://dep.wv.gov/WWE/getinvolved/sos/Documents/SOPs/BEHI-Overview.pdf, retrieved 8/4/2020.

Moore, I. D., and Wilson, J. P., Length-slope factors for the Revised Universal Soil Loss Equation: Simplified method of estimation, *J. Soil and Water Conserv.* 47(5), 423-428, 1992.