A GIS-based optimization analysis of the Smock Riverwalk Trail

Noah Bebee, Maddie Betts, Maryellen Scowden, Elisia Wright

Introduction

Land trusts are non-profit organizations built to conserve land. Trusts can conserve land by either owning the property or holding conservation easements, which allow the trust the ability to conserve the land without owning it (Parker 2004). French Creek Valley Conservancy is a land trust organization based in Meadville, PA that owns 22 properties and easements throughout the French Creek watershed in northwestern Pennsylvania. The property of focus, Smock Riverwalk, is owned outright by the French Creek Valley Conservancy and is located along French Creek and has about 800 feet of creek frontage as well as a boat launch for recreational river access. This property is of great importance to the ecology of French Creek and the Conservancy because much of it lies within French Creek's riparian buffer.

Riparian buffers are extremely important for stream ecosystems. They provide shade and prevent agricultural and urban runoff. The plants in riparian buffers hold the soil together and protect against erosion of soil along waterways. These plants also provide leaf litter and other organic matter that is used by many organisms for habitat and reproduction. Riparian buffers are important for carbon regulation and acid-base regulations in streams (Kuglerová et al. 2014). Removing riparian buffers can impact the streams in many ways such as decreasing habitat, increasing water temperature, soil erosion and the leaking of chemicals and harmful substances into waterways. Trails that are designed using GIS in a way

that takes these factors into consideration can protect against the destruction of these buffers, greatly improving water quality (Kuglerová et al. 2014).

Hiking can also negatively impact land if trails are not optimized. Hikers can trample plants and create space for invasive species to grow. In a study conducted by the University of Minnesota, the plant life along trails on two properties in New Hampshire were observed. Many of the plant species were impacted with even low trampling (250 passes) (Leonard 1985). The trampling off the trail resulted in twice as much compaction to the spruce-fir forested area compared to the hard and softwood areas. Human pathogens can also be spread by hikers and spread into local waterways. Pathogens can be spread by hikers' shoes when walking along a trail (Pickering et. al 2010). Human pathogens can easily be spread by human waste and create runoff into local waterways. This can cause E.coli outbreaks in areas where there is high water recreation (Li et al. 2019).

Leave No Trace (LNT) operates under seven core principles (Simon and Alagona 2009). These seven core principles, when applied to LNT trails, are designed to mitigate the environmental impact of the surrounding ecosystem in recreational areas. With increased use and weathering over time, trails becomes more visibly degraded and hikers will tend to veer off the trail causing it to widen and destroy nearby vegetation (Guo et al. 2015). Hikers that walk in undesignated areas, especially in riparian areas, can cause rapid deterioration of the ecosystem and threaten the ecological integrity of the surrounding habitat. Undesignated trail use leads to infiltration of protected landscapes and habitats, damaging vegetation, tarnishing aesthetics, as well as negatively impacting visitor experiences. Monitoring protocols involves gathering timely data regarding the condition, extent and distribution of these unwanted trail networks. Educational trailside messages and physical barriers influence hiker behavior and reduce the usage of informal trails by 97 percent and are an effective preventative measures against the formation or continuation of informal trail systems (Schwartz et al. 2018).

The geology, climate, topography and vegetation of the surrounding environment are large indicators of erosion susceptibility on a trail. Areas with high precipitation rates, steep landforms, close proximity to streams, and fine soil textures are at greater risk for trail degradation. In order to plan a trail optimal for the environment it is important to take into account trail alignment, since it is a significant contributor to soil loss (Olive et al. 2009). Undesignated and muddy trail use contributes to soil loss and trail widening because hikers are more likely to veer off-trail to circumvent those areas (Marion et al. 1996). Hence, visitor management, trail optimization and trail maintenance are vital to maintain a successful, sustainable trail system. Prior to constructing the trail, accounting for trail grade, slope alignment angle, stream crossings, soil type, and sensitive resources will reduce future maintenance. Areas with wet soils should have adequate drainage systems implemented to prevent trail widening such as parallel drainage ditches, using geosynthetics, and puncheons. Tread-hardening techniques can be used during construction or maintenance periods (Marion et al. 2004).

With an understanding of behavior trends on the trail and how undesignated trail use can lead to harmful environmental effects, more efficient management can be implemented through means of various assessment techniques. Trail surveys such as trail attribute inventory, trail condition assessment and trail prescriptive management assessment are common ways to assist in managing trail systems. These surveys take into account GPS mapping and GIS technology to evaluate aspects of the trail and the surrounding ecosystem (Marion et al. 2012). Point sampling and problem assessment methods yield different types of quantitative information such as tread width and exposed soil or excessive with and secondary treads respectively (Marion et al. 2001). All trail users behave differently and a complete understanding of where people frequent and the means of transportation used on the trail can allow for more effective planning and management. Recreation within parks and protected areas (PPA) is widely affected by spatial behavior, or the behavior in different areas of the PPA (Riungu et al. 2018). When they are visualized or quantified through GPS or GIS technology there is an opportunity for park managers to

assess recreation within the PPA to preserve the surrounding ecosystem. Lack of this knowledge means that trail managers will be unaware of activity both on and off the trail and will be unable to properly assess the implementation of direct and indirect barriers. GIS-based support can serve as a facilitator to discuss future planning in the area in a more visual and applicable manner, which will result in more controlled and populated use of the trail. Recreational suitability maps utilize GIS to portray subjective landscape preferences through surveys and peoples' actual preferred locations (Kienast et al. 2012). It is important to make sure the public is aware of what the trail provides in terms of recreation as well as its ecological importance. An educated public will control their behavior more than the uneducated. Even though all hikers will behave differently on the trail it is still important for planners and municipal authorities to utilize spatial behavior and GIS or GPS information, as well as recreational suitability maps to create a more controlled recreational outdoor environment.

The Smock Riverwalk property in Meadville Pennsylvania is located next to French Creek and has an existing trail. The property is owned by the French Creek Conservancy. This property is a Riparian Buffer and is crucial for the buffering of chemicals and soil from reaching French Creek. For this reason, the conservancy does not wish to create any more trails that go closer to the creek. It is known that a non-optimized trail can cause huge impacts on the environment around the trail. The problem with the Smock Riverwalk trail is that there is no access to see the creek except for a boat launch that was added to the property in 2018. There are many tracks where people are trampling vegetation to access the creek. The trampling of vegetation leads to an increase in invasive species that are currently on the property. There is also widening of the trail at the beginning and end due to the mud that is present. This over time can lead to more widening to avoid this muddy area. The off-trail usage can also lead to an increase in soil erosion and invasive species. The trail also has several areas were there is exposed landscaping tarp.

The goal of this project is to conduct a GIS-based suitability analysis to determine if the trail is in the optimal location for the property. If the trail is not in the optimal location, then it would be proposed that it be moved to a more optimal location with access to the stream. The project is also going to look at the different areas of concern (muddy areas, tarp areas) and create a plan for the repair/maintenance to these areas.

Methods

All spatial analysis was conducted using ArcGIS Pro 2.3.1 (ESRI 2019).

Study Region

The Smock Riverwalk, owned by the French Creek Valley Conservancy, is an 8-acre property located off of Wadsworth Avenue in Meadville, PA. It is moderately well-forested with dense underbrush and lies directly adjacent to French Creek, with much of the property falling within the recommended width of French Creek's riparian buffer (Lehigh Valley Planning Commission 2011). One trail and one boat launch have been pre-established within property boundaries. The trail is approximately 0.3 miles in length, with two points of entry (Figure 1).

Figure 1: Smock Riverwalk property boundary and pre-established trail and boat launch.

Input variables

One of the most important benefits of a riparian buffer is preventing excess soil from entering the waterway (Parkyn 2004). Given that much of the Smock Riverwalk property lies within French Creek's riparian buffer, the land use choices made here directly correlate with the amount of soil entering the stream. The most easily identified source for potential soil erosion is the established trail. Although soil erosion has been cited as the most widespread trail impact, and often can only be fully remedied with expensive management actions, it can be somewhat prevented by incorporating different factors into trail design (Olive and Marion 2009). We considered three different factors that contribute to soil erosion in our analysis. These are described below.

Table 1: Factors presented by Olive and Marion in their 2009 study of soil loss on recreational trails. The three factors used in our study were determined from this list.

Factors	Attributes contributing to greater erosion susceptibility	Citations
Environmental		
Geology	Soils with homogeneous texture soils; fine- and coarse-grained soil textures	Bratton et al., 1979, Bryan, 1977, Burde and Renfro, 1986, Helgath, 1975, Meyer, 2002, Whinam and Comfort, 1996
Climate	High precipitation rates	
Topography	Steep landforms; high elevation; proximity to rivers and streams	
Vegetation	Mature forests; mesic forests; broad-leafed ground vegetation	
Managerial		
Trail design	Steep trail grades; trails aligned congruent with prevailing slopes; tread not outsloped; lack of grade reversals	Birchard and Proudman, 2000, Cole, 1989, Farrell and Marion, 2002, Hesselbarth and Vachowski, 2000, IMBA, 2004

Maintenance	Non-existent or ineffective tread drainage features	
Visitor-related	Failure to regulate type or amount of use; lack of low-impact behavior education	
Use-related		
Use amount	High use in sensitive vegetation and/or soil types	Cole, 1983, Deluca et al., 1998, Farrell and Marion, 2002, Leung and Marion, 1999b, Sun and Liddle, 1993
Use type	Improper use type for environmental and design factors	
User behavior	Failure to stay on maintained path; high use during wet conditions	

Environmental Factors

Slope

Slope contributes greatly to soil erosion. The steeper the slope, the more soil erodes during a rain event (Watson and Laflen 1986). Therefore, we designed our analysis to favor more gentle slopes along Smock Riverwalk, which would reduce runoff velocity and soil loss. A raster-based slope dataset was used for our analysis. We chose to reclassify slopes between 0-5% as a 5, 5-10% a 3, and >10% a 1, based on a

study by Assouline and Ben-Hur, 2006, which discovered that there was relatively little change in soil erosion among slopes less than 10%, but a dramatic, exponential increase in soil erosion as soon as slopes surpassed 10% (Figure 2).

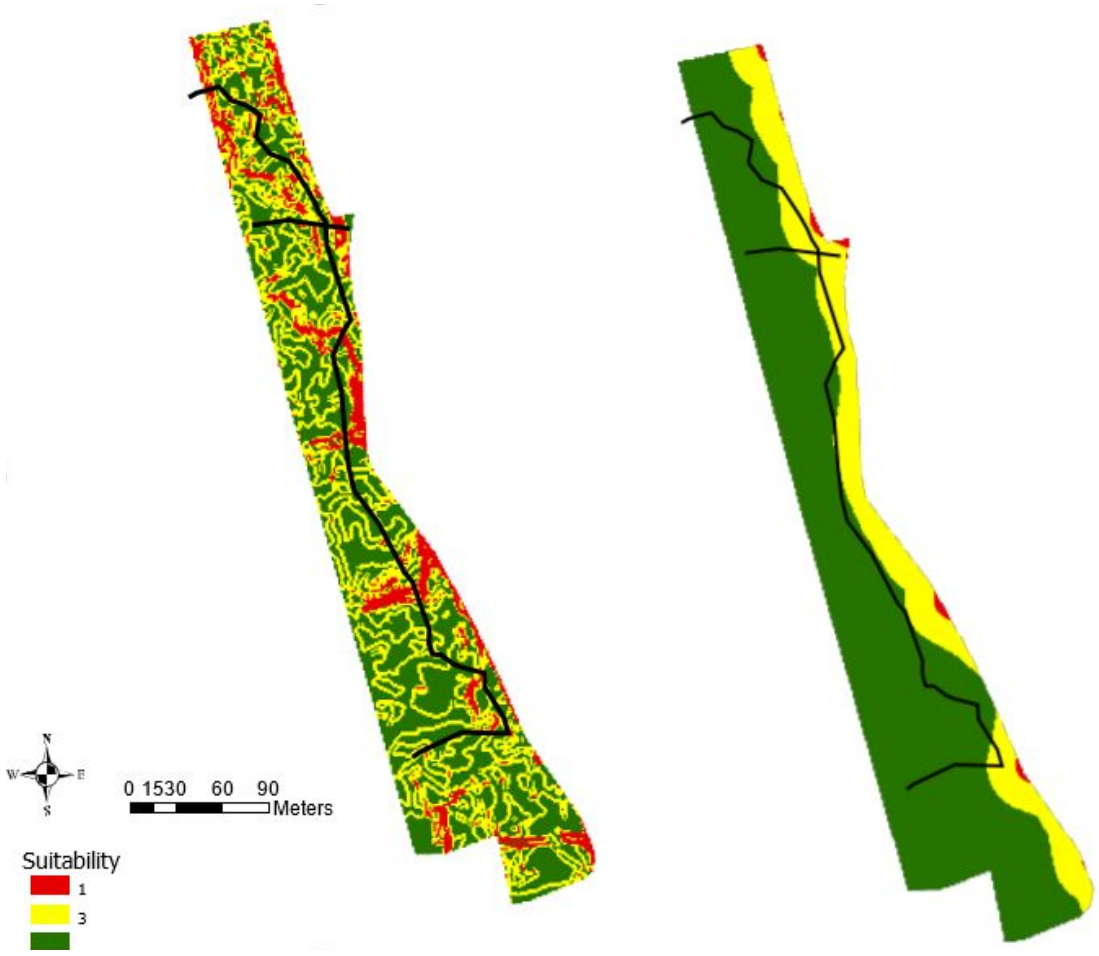

Figure 2: Ranked suitability indices for slope (left) and proximity to stream (right).

Proximity to Stream

Riparian buffers remove excess sediment from runoff before it enters the stream. The recommended width of riparian buffers for sediment control is 50-160 feet total, or 25-70 feet on either streambank (Lehigh

Valley Planning Commission 2011). Therefore, we established our reclassified values so <25 feet away from the stream was a 1, 25-70 feet away was a 3, and >70 feet was a 5 (Figure 2).

Managerial Factor

Non-existent or ineffective tread drainage features

Ineffective tread drainage along trail can lead to trail widening, muddiness, and visitors straying off the established trail--all of which contribute to soil erosion (Olive and Marion 2009). Along the Smock Riverwalk trail, there are multiple areas of muddiness and many points where underlain tarp and netting (assumed to have been originally placed to control soil loss) have become exposed. These areas were marked with a GPS and buffered by 1 meter for netting and 2 meters for mud and classified as "No Data." They were not large enough areas to be seen from the scale used in Figure 2, and were therefore not included in the Figure.

Sensitivity Analysis

Slope and proximity to stream raster datasets were overlaid and given equal weights of 50%. The resulting map therefore depicts reclassified values from both slope and proximity to stream data. The established trail and boat launch were included on the map in order to assess its current contribution to soil erosion (Figure 3).

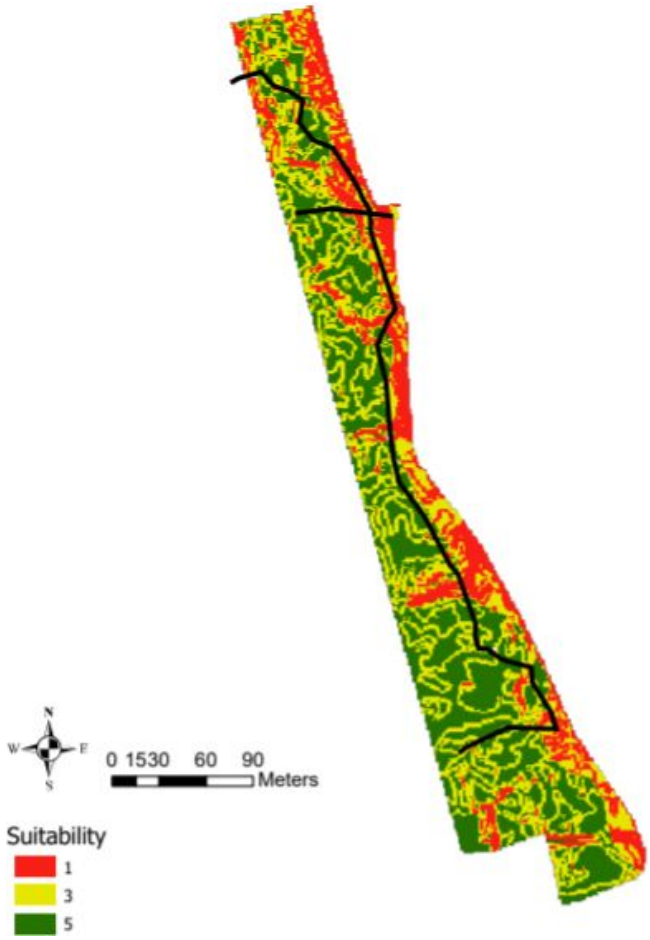

Figure 3: Composite map of two weighted variables with buffered drainage features removed. Red (1) denotes areas most unsuitable for trail placement. Current trail placement is represented by dark black line.

Results & Discussion

A composite map was created by overlaying slope and proximity to stream raster datasets and giving both inputs equal weights of 50%. This map therefore depicts reclassified values from both slope and proximity to stream data. The established trail and boat launch were symbolized on the map as black lines in order to assess their current contribution to soil erosion (Figure 3).

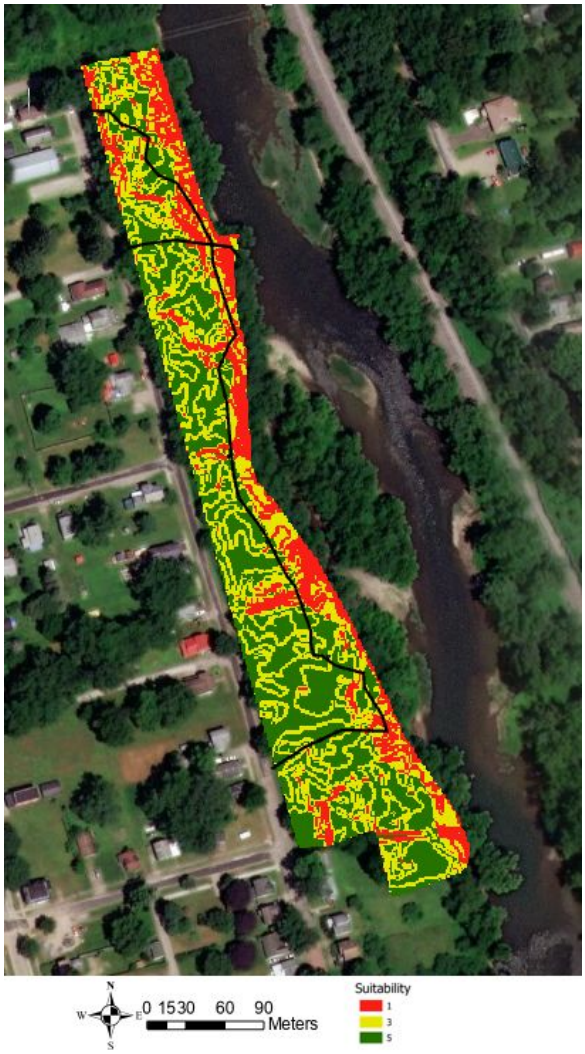

Figure 3: Composite map of two weighted variables (slope and proximity to stream). Green (5) denotes areas most suitable for trail placement after combining variables, red (1) denotes areas most unsuitable. Current trail placement is represented by black line.

We determined from this composite map that the current trail/boat launch on the Smock Riverwalk property is not located in a way that prevents soil erosion and damage to the riparian

ecosystem and French Creek. Much of the trail cuts directly though large swaths of unsuitable land and narrowly borders the streambank. The boat launch (seen near the top of the property as the black line that sits east to west) would be better situated along the south side of the property, in the green area of the map just north of where the trail changes directions from east-west to north-south. The trail itself would be better located if it were pushed westward, as areas along the west side of the property appear to be more suitable overall, given the variables we considered. However, modifying trail location now would likely cause more damage to the riparian ecosystem than it would solve, and because of this we recommend simply using the methods developed here for planning additional trails on additional properties.

When considering GIS suitability analysis, the applications are widespread. Suitability maps present an analysis of an entire property based on a variety of factors. Looking past Smock Riverwalk, the methods described in this study can be applied to any property. When planning to alter a trail system or create a new trail, many people support the integration of GIS analysis because it acts as a facilitator for, in this case, city planners to decide the best course of action (Pietilä 2018).

GIS is a critical tool that is useful for determining placement of new trails on properties. Without optimal trail placement, the trail can lead to erosion, invasive species and trampling of native species (Assouline & Ben-Hur, 2006). Trails that are built too close to streams can harm the natural riparian buffer and negatively impact the waterway. A GIS analysis and the methods used in this research should be considered in future properties to reduce the impact that negative trail placement can have on French Creek Conservancy land.

There are various areas of concern involving muddiness and matting along the trail. Geosynthetics have previously been applied to the trail to help prevent invasive plant growth and sedimentation. The matting has now become hazardous; exposed matting can endanger the well-being of visitors by increasing their likeness to trip over it. The matting is also no longer of use as it can be easily lifted up in some areas of the trail. The exposed geosynthetics also negatively impacts the aesthetics of the

trail, as does muddiness. Several sections of the trail have become increasingly muddy. Since the matting is no longer being held in place, the ground will continue to become more saturated and muddy. These areas should be avoided in order to prevent undesignated trail use and trail widening.

The mission statement for the French Creek Valley Conservancy is: "To promote the environmental integrity of the French Creek watershed, and to advocate the protection of its natural resources for the aesthetic, ecological, recreational, and economic benefit of all, through the coordination of land protection, education, and research." Protecting and promoting environmental integrity on French Creek Valley Conservancy properties requires that proper measures be when designing and building new trails. GIS and the methods used in this research should be used for future trail building projects to reduce the impact that trails have on the environment.

Based on the suitability map (Figure 3) there are many segments of the trail that fall in unsuitable areas that appear to be in close vicinity to the identified muddy and exposed netting areas. Under optimal circumstances, the trail system would be planned using similar GIS suitability methods prior to the construction of the trail in order to minimize erosion and soil loss. However, since the trail is already established and in a sensitive riparian zone, attempting to optimize the current trail system would be more detrimental over time than if the LNT trail were left as is. In any case, only one third of all drainage issues would be solved by relocating a trail because the surrounding area does not change drastically in elevation. Hence, where altering the current trail system is not feasible, improving drainage features to minimize erosion and soil loss and installing elevated walkways (puncheons) are the most effective solutions (Root & Knapik 1972; Bayfield & Lloyd 1973). Utilizing elevated walkways around muddy areas would also mitigate undesignated trail usage and trail widening. Research demonstrates that if a trail becomes muddy due to poor drainage, hikers are more likely to veer off-trail to circumvent those areas. This contributes significantly to excessive trail widening (Marion et al. 1996). These features would not

only help preserve the riparian area more effectively, but make the maintenance process much more manageable as well.

Currently, tarp matting has been laid down on the trail, however it is not sufficient. There are other geosynthetics that can be utilized that require less maintenance and be better suited for this specific trail. Due to being located in Meadville, Pennsylvania, this trail system is prone to wet weather conditions daily. In addition to using traditional trail construction methods for wet areas such as puncheons, geosynthetics should also be utilized to mitigate soil compaction, sedimentation, undesignated trail use, as well as unhappy visitors. Geotextiles are the most commonly used geosynthetics, as they are used for separation and reinforcement over wet soils. They allow water, but not soil, to seep through and are low cost, flexible and easy to use. Geonets are used for separation, reinforcement and drainage. They provide more reinforcement than geotextiles, but are more costly. These geosynthetics allow for excess surface moisture to seep through, even if located on a grade or slope. Tread fill material, such as gravel or rocky soil, should also be used in addition with geosynthetics. Organic, silt or clay soils should be avoided due to their low permeability (Monlux 1995). Replacing the current matting with geosynthetics would allow for minimal maintenance while reaping greater benefits such as less sedimentation and muddy areas.

GIS should be used in future projects with the French Creek Valley Conservancy to limit the environmental impact of trails. The Conservancy should also consider trail access to the water to limit the impact of trampling. Water access on the Smock Riverwalk property is not an option due to the flooding that occurs along the side of the creek. Other properties that have less flooding could benefit from an access point from the trail. In the Smock Riverwalk property, there was a lot of undesignated trail use to gain access to the creek which leads to trampling of native vegetation and an increase of invasive species (Leonard, McMahon, & Kehoe, 1985).

There are few significant limitations in this project. The property, Smock Riverwalk, is an 8 acre property, with recreational areas. Of these 8 acres, the trail is approximately 0.25 miles in length and only

about 300 feet border French Creek. Altering a trail of this size on such a sensitive ecological property would cause more damage than benefit, however similar methods should be used for trail planning at future properties. Furthermore, some factors were unsuccessful while performing GIS analyses of the property. Elevation and soil were consistent across the entire property. We attempted to run euclidean distance for areas of concern, such as muddy and exposed netting areas, but this tool factored in the entire property. In any case, a buffer tool was used. Finally, there was limited time to complete a full GIS analysis of the Smock Riverwalk property because it was only a semester long project.

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