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Cost Benefit Analysis and Beyond: Stream Restoration in Richmond, Virginia

Abstract

This research assessed the costs and benefits of six recent stream restoration projects in Richmond, Virginia within the context of the Chesapeake Bay Total Maximum Daily Load (CB TMDL) pollutant reduction requirements. In order to meet these requirements, state and local governments promoted stream restoration as an important way to reduce Bay-wide inputs of nitrogen, phosphorus, and total suspended solids. The overall intention of this paper was to holistically evaluate the risks and positive impacts associated with stream restoration, with a focus on Little Westham Creek, a stream restoration project located on the University of Richmond campus. I hypothesized that Little Westham Creek provides the lowest cost per unit of pollutant removal relative to the other five projects studied. A cost benefit analysis of total budget estimates and annual reduction estimates of nitrogen, phosphorus, and total suspended solids was used to determine which of the six projects provides the lowest cost per unit of pollutant removal. The Little Westham Creek stream restoration project yielded the lowest cost per unit of pollutant removal. This cost benefit analysis was used as a starting point for evaluating the costs and benefits of stream restoration, as a more holistic analysis of stream restoration projects was explored from an ecosystem services perspective. The value of key ecosystem services connected to stream restoration was explained, both from an eco-centric and anthropocentric point of view. Finally, suggestions for improvements to future stream restoration projects and other Bay-wide water quality improvement initiatives were presented based on past successes and failures in the six stream restoration projects studied.

Introduction and Background Information

In the face of climate change, increasing urbanization, and water pollution, stream restoration has been identified as a potential solution to decreasing water quality in the United States. In particular, stream restoration is considered a Best Management Practice (BMP) for improving storm water management, especially in urban watersheds (Williams et al., 2016).

Overall, the aim of stream restoration project is to return the stream “to a close approximation of its remaining natural potential” (US EPA, 2000). The success of stream restoration projects is often determined by measuring levels of nitrogen (TN), phosphorus (TP), and total suspended solids (TSS), which are indicators of water quality (Williams et al., 2016, p. 1227). These nutrients and pollutants can be measured pre- and post-restoration, allowing for a comparison of stream water quality before and after the restoration project has been completed. In some cases, these projects contribute to local, state, or regional pollutant reduction requirements, and are therefore motivated by extrinsic factors. Alternatively, other projects are intrinsically motivated, as they aim to improve water quality, other ecosystem functions, and human-environment interaction with the stream habitat.

A prime example of extrinsic motivation to improve water quality is present in the Chesapeake Bay Total Maximum Daily Load (CB TMDL). In 2010, the US EPA announced that it would be implementing a TMDL program, which essentially acts as a “pollution diet” for the entire Chesapeake Bay watershed. The purpose of the TMDL is to “restore clean water in the Chesapeake Bay and the region’s streams, creeks and rivers” (Chesapeake Bay TMDL Executive Summary). As Pennino et al. explains, “the growing impacts of urbanization on watershed nutrient exports have contributed to coastal eutrophication and hypoxia both regionally and globally” (2016, p. 3419). The Chesapeake Bay is no exception to these water quality threats, as it has been plagued by toxic algal blooms that suffocate both plant and animal life in the Bay. These “dead zones” threaten biodiversity, nutrient recycling, and the success of commercial fisheries on a regional scale (CB TMDL Executive Summary, 2010). Six states are required to comply with the TMDL, including Virginia, Maryland, Delaware, Pennsylvania, New York, and West Virginia, along with Washington D.C. The involvement of these actors at the regional, state, and local levels requires careful planning and collaboration in order to collectively reduce the impact of nutrients and sediment on the health of the Bay.

As is the case with the CB TMDL, reductions in TN, TP, and TSS in each state are determined and monitored by the US EPA in order to ensure improvements to watershed health (Section 4 of the Chesapeake Bay TMDL: Sources of Nitrogen, Phosphorus and Sediment to the Chesapeake Bay). Within freshwater streams, “eutrophication, the enriching of waters by excess nitrogen and phosphorus, reduces water quality in streams, lakes, estuaries and other downstream waterbodies” (Meyer et al., 2013, p. 13). Furthermore, harmful algal blooms caused by cultural eutrophication can cause a myriad of human and environmental concerns, including hypoxic dead zones, poisoning of municipal drinking water sources, health risks for both humans and animals (Meyer et al., 2013, p. 13). In 2009, Virginia was the top polluter of

TP and TSS (43% and 41% respectively), and the second highest polluter of TN (27%) (Section 4 of the CB TMDL). Undoubtedly, when the TMDL was announced, Virginia had a lot of improvements that needed to be made in order to protect the health and well-being of its waterways, plants, animals, and people. Directly following the announcement of the implementation of the CB TMDL, there was immense pressure to come up with a plan to comply with this legislation as quickly as possible.

Flow of both nutrients and sediment through the stream can be reduced through lowering the risk of bank erosion and altering the hydrologic flow of the stream. This can be accomplished through various changes to the physical form of the stream. By lowering the bank height, there is a lower risk of sediment being washed into the stream through erosion, especially during heavy precipitation events (Craig et al., 2008, p. p. 535). Lowering the bank height also connects the stream with its natural floodplain so that in during heavy precipitation events, sediment and nutrients can be deposited into the floodplain, instead of being swept downstream (Kaushal et al., 2008, p. 799), see Image 1. As Mayer et al. explains, sediment and nutrient reductions occur when bank height is lowered because "groundwater is in contact with carbon rich surface soils, and mixing of groundwater and stream water with variable oxygen and redox levels can promote coupled nitrification-denitrification" (2010). Also, changing the path of the stream can allow for sediment and nutrients reduction (Craig et al., 2008, p. 535). In stream restoration, straight and channelized streams are restored to a more natural, meandering path (mimicking typical pre-industrial stream conditions) in order to slow down the flow of water and allow nutrients and sediment to settle out into the streambed or floodplain (Craig et al., 2008, p. 535), see Image 2.

Beyond improvements to water quality, stream restoration is a tool used to improve the entire ecological health of a stream ecosystems. Ideally, the improvements made during stream restoration positively influence the variation, amount, and impact of ecosystem services that are provided by the stream to surrounding areas. According to Palmer and Filoso, ecosystem services provide direct benefits to humans (2009, p. 575). However, ecosystem services do not need to be understood just as benefits to humans, but should more broadly be viewed as benefits to the interconnected living and non-living parts that make up the ecosystem itself. Recently, individuals and organizations, both private and public, have gained an increased appreciation and understanding of these ecosystem services and the benefits they provide (Sarvilinna et al., 2017). Some of these additional ecosystem services include natural storm water management, increased groundwater recharge, carbon recycling/storage, biodiversity, and increased access to recreational, educational, and research opportunities in and around the stream (Meyer et al., 2003; Pander & Geist, 2013), see Images 3 and 4.

Through a cost benefit analysis (CBA) of both the reductions in TN, TP, and TSS, along with the additional ecosystem services provided by stream restoration projects, this paper seeks to provide a holistic evaluation of the costs and benefits of the City of Richmond's investments in urban stream restoration projects in connection with the CB TMDL. Based on a cost benefit analysis, this paper posits that instead of having similar costs per unit of pollutant removal ($/lb), the costs and benefits of recent stream restoration projects in Richmond, Virginia will vary. Specifically, it hypothesizes that Little Westham Creek, a restoration project located on the University of Richmond campus, will provide the lowest cost per unit of pollutant removal ($/lb). However, the analysis will go beyond simple cost benefit analysis, arguing that while evaluating TN, TP and TSS reductions is necessary for local and state governments to meet their "pollution diet" requirements, there are additional ecosystem services provided by stream restoration that should be valued. By expanding the lens of analysis beyond annual pollutant reductions, scientists, engineers, stream restoration experts, and local, state, and regional decision-makers can more holistically understand and value stream restoration projects and their immense transformative potential in relation to the human and natural habitats that surround them.

Methods

In order to complete the CBA portion of this analysis, I first had to find budget information and annual reduction estimates of TN, TP, and TSS for recent stream restoration projects in Richmond, Virginia. I began this search on RVAH2O's website (rvah2o.org), where I discovered both budget and pollutant reduction estimates for Pocosham Creek and Rattlesnake Creek. RVAH2O is an initiative that is led by the Richmond Department of Public Utilities, and in 2017, they released a "Clean Water Plan" which sets goals for the city to "efficiently reduce pollutant discharges into our rivers and streams" (RVAH2O: Planning for the Future). On RVAH2O's website, I also found a strategy cost estimation document that outlines the various costs of water quality improvement strategies, including an estimate of the cost of stream restoration. The estimate provided is $645/linear foot of stream, which I used to estimate the cost of implementing the Little Westham Creek project (Appendix 5, Strategy Cost Estimation, rvah2o.org, 2017). This cost estimate just takes into account the costs of implementing the stream restoration strategy itself—not any operations and management costs post-restoration.

I then searched through documents from the US Environmental Protection Agency (EPA), the Virginia Department of Environmental Quality (DEQ), the City of Richmond Office of Budget and Strategic Planning, and project materials from Resource Environmental Solutions (RES). Eventually, I came across Richmond's TMDL Action Plan that was published during Phase II of the TMDL implementation (2015). This contained pollutant removal and budget estimates for Pocosham Creek, Rattlesnake Creek, Reedy Creek, Albro Creek, and Maury Cemetery. Again, these budget estimates only account for the costs of implementing the stream restoration strategy itself—not any operations and management costs post-restoration.

However, the TMDL Action Plan did not contain budget or pollutant reduction estimates for the Little Westham Creek project. I was able to use Appendix 5 of the Clean Water Plan to multiply the total length of the restoration project (2300 linear feet) by the $645/linear foot of the stream restoration (Appendix 5, Strategy Cost Estimation, rvah2o.org, 2017). This yielded an estimate of $1,354,500. I also contacted Bob Siegfried from RES, and he provided me with TN, TP, and TSS reduction estimates for the project. These estimates, along with those previously mentioned from the TMDL Action Plan were used to complete the calculations in Table 1. While working on my project, I was made aware of a second set of estimates for both Pocosham and Rattlesnake Creek. This data was provided by Grace LeRose to Rob Andrejewski at an RVAH2O update meeting on November 18, 2019. These additional estimates varied greatly from those present in the TMDL Action Plan from 2017, and are presented in Table 2.

Finally, in order to complete the CBA, I researched various methodologies. According to Sanders et al., CBA can be defined as "an analytic tool for estimating the net social benefit of a program or intervention as the incremental benefit of the program minus the incremental cost, with all benefits and costs measured in US dollars" (2016, p. 1094). I tried to find a weighting scheme that would represent the relative impact of TN, TP, and TSS, however, in the end I chose to weigh TN, TP, and TSS equally, as the focus of this research was not to assess the relative importance of each pollutant, but instead to evaluate the overall pollutant reduction impact of each project in relation to its total cost. For the CBA, the TN, TP, and TSS reduction estimates were added together for each project (total pollutant reduction in pounds/year). Then the total cost of the project was divided by the total pollutant reduction. This yielded the cost per unit of pollutant removal ($/pound).

Results

In both Table 1 and Table 2 are the estimated reductions of TN, TP, and TSS and for all six projects (lbs), the aggregated estimated reductions (lbs), the cost of implementing the stream restorations ($), and the cost per unit of pollutant removal ($/lb). In Table 1, it is clear that Little Westham Creek provides the lowest cost per unit of pollutant removal ($2.84/lb). This is about 8.5 times lower than the highest estimate of cost per unit of pollutant removal, which is estimated for Albro Creek as $24.83/lb (Table 1). This supports my hypothesis that Little Westham Creek provides the lowest cost per unit of pollutant removal compared to other recent stream restoration projects in Richmond.

The data provided in Table 2 does not indicate as significant of a difference between the cost per unit of pollutant removal of Little Westham Creek ($2.84/lb) and the other two projects: Pocosham Creek ($6.81/lb) and Rattlesnake Creek ($6.41/lb). Little Westham Creek is only about 2.5 times lower than both Pocosham Creek and Rattlesnake Creek, which have very similar costs per unit of pollutant removal to one another (Table 2). Based on the Table 1 data, Pocosham Creek had a cost per unit of pollutant removal of $9.27/lb, which is not much higher than the estimate presented in Table 2 ($6.81/lb). Conversely, Rattlesnake Creek saw a dramatic decrease in its estimate from Table 1 ($16.35/lb) to Table 2 ($6.41/lb). The discrepancies between these two data sets and their implications will be analyzed further in the discussion section of this paper.

	Reedy Creek	**Maury Cemetary**	**Albro Creek**	**Pocosham Creek**	**Rattlesnake Creek**	**Little Westham Creek**
Length of stream restoration (linear feet)	2200	1980	1281	5990	1500	2300
Nitrogen (lbs/yr)	165	148.5	96.08	449.25	112.5	3500
Phosphorus (lbs/yr)	149.6	134.64	87.11	407.32	102	1375
TSS (lbs/yr)	98736	88,862.40	57491.28	268,831.20	67320	472000
Cost ($)	1270000	905000	1,432,000	2500000	1104000	1354500
Total Pollutant Removal (lbs/yr)	99050.6	89145.54	57674.47	269687.77	67534.5	476875
Cost per unit of pollutant removal ($/lb)	**12.82**	**10.15**	**24.83**	**9.27**	**16.35**	**2.84**

Table 1: Cost Benefit Analysis calculations for all six stream restoration projects. Data for Reedy Creek, Maury Creek, Albro Creek, Pocosham Creek, and Rattlesnake Creek from the Richmond TMDL Action Plan (2015). Data for Little Westham Creek provided by RES and cost estimate derived from Appendix 5 of the RVAH2O Clean Water Plan. Length of each project is included for reference.

	Pocosham Creek	Rattlesnake Creek	Little Westham Creek
Length of stream restoration (linear feet)	5500	1700	2300
Nitrogen (lbs)	4600	1072	3500
Phosphorus (lbs)	1061	494	1375
TSS (lbs)	354000	170000	472000
Cost ($)	2450000	1100000	1354500
Total Pollutant Removal (lbs	359661	171566	476875
Cost per unit of pollutant removal ($/lb)	**6.81**	**6.41**	**2.84**

Table 2: Cost Benefit Analysis calculations for three restoration projects. Data for Pocosham Creek and Rattlesnake Creek provided by the Department of Public Utilities at an RVAH2O update meeting on November 18, 2019. Little Westham Creek pollutant reduction estimation data was provided by RES. Length of each project is included for reference.

Discussion

First, I will discuss the limitations of the CBA methodology I used. By using an equally weighted CBA and the exclusion of the stream restoration, I was able to simplify my analysis. **However**, there may exist a better weighting scheme that would more accurately represent the relative impact of nitrogen vs. phosphorus vs. total suspended solids on overall water quality. If I had more time and expert knowledge of the specifics of different types of cost-benefit analysis methodologies, perhaps I could have applied a weighting scheme that would better take into account the relative importance of each pollutant. Also, I chose not to incorporate the length of the stream restoration project (linear feet) in the CBA calculations. The projects range in length from 1281 linear feet to 5990 linear feet. Had the stream restoration lengths been incorporated into the calculations, it is possible that the cost per unit of pollutant removal per linear foot of restoration ($/lb/linear foot) would have yielded values that would not have supported my hypothesis.

Based on the data presented in both Table 1 and Table 2, the differences between the Rattlesnake Creek and Pocosham Creek estimates cannot be ignored. The discrepancies between the data presented by Richmond's TMDL Action Plan (Table 1) versus the data provided by the Richmond Department of Public Utilities (Table 2) are dramatic. This makes comparing the projects much more difficult, as it is nearly impossible to determine which estimates are the most accurate. One possible explanation for the drastic differences between these two data sets is that the TMDL Action Plan was created in 2015, whereas the recent data from the Department of Public Utilities was provided in 2019. The estimates that were presented in the Action Plan were calculated based on expected changes in bank height and erosion rates caused by the implementation of stream restoration strategy (pre-data), whereas the 2019 data may have been based on actual structural changes made to the streams (post-data). Therefore, the 2019 data may be more accurate, because it is based on post-construction observations of changes to the stream, instead of hypothetical estimates proposed in the Action Plan.

Nevertheless, the absence of this post-data from Reedy Creek, Albro Creek, and Maury Cemetery makes this analysis more complicated. A partial restoration of Albro Creek was technically completed in 2014, however, shortly after a heavy precipitation event, the newly "stabilized" banks were blown out by heavy water flow, allowing hundreds of pounds of nitrogen, phosphorus, and TSS to enter the creek. The post-restoration data from the Albro Creek project is not published on the RVAH2O website nor the Richmond Department of Public Utilities (DPU) website, even though the project was mentioned in the TMDL Action Plan (2015). The apparent failure of the Albro Creek project prompted strong pushback amongst community members in Forest Hill, which is the neighborhood adjacent to the proposed site of the Reedy Creek stream restoration project. According to the Reedy Creek Coalition's website, the DPU never consulted the community regarding the project, chose a high-risk project site, and did not address the local history of the area when the project details were finally released to the public (Reedy Creek Coalition website, 2016). Furthermore, based on the City's past lack of response and appropriate action in relation to the Albro Creek project, Forest Hill residents were hesitant to trust the DPU's proposed construction and maintenance plan for Reedy Creek. Overall, many local residents felt that the DPU was hyper-focused on gaining stream restoration credits quickly and with minimal effort, instead of taking into account the long-term impacts that this project would have on the stream itself, the habitats that surround it, and the community that uses it for recreation and depends upon it for natural storm water management.

According to the DPU, the Pocosham Creek project was fully completed in 2019, and construction was carried out by Hazen and Sawyer. The stream restoration included reconnection to the natural flood plain (60 acre-feet of temporary floodplain), riffles, J-hooks, and rock vanes added to the stream itself, preventing both vertical and horizontal stream erosion (Hazen and Sawyer website, 2019). Post-construction monitoring of the stream is guaranteed for five years. Additionally, the Rattlesnake Creek project is currently in construction bidding (information provided by Grace LeRose via email, October 30, 2019). Finally, while I was able to receive estimates of TN, TP, and TSS reduction estimates from RES for the Little Westham Creek project, the DPU was not willing to release any budget estimate information for the project. This presented a huge obstacle for this research project, because without a budget estimate for Little Westham Creek, I would not be able to compare the cost per unit of pollutant removal for this project with the other five stream restorations. It is unclear why the DPU is not willing to release this information, and it connects to the larger issue of a lack of transparency in the City's budgeting and planning for these stream restoration projects. From the perspective of many Richmond residents, these stream restoration projects may have more risks than benefits, and appear as projects that are designed to "check off a box" on a long list of water quality improvement measures connected to the CB TMDL, instead of acting as well-designed and managed investments for the future of Richmond water quality. This emphasizes the extrinsic motivation of many of these stream restorations, instead of the intrinsic motivation to provide clean and safe water for Richmond residents and the plants, animals, and communities that are affected by downstream water quality in the James River and Chesapeake Bay.

As the members of the Reedy Creek Coalition expressed, the benefits of stream restoration on an ecosystem level are not certain. In particular, experts in ecology claim that "concerns have been raised over the potential loss or degradation of ecosystem attributes that are not the focus of management or restoration efforts" (Palmer et al., 2014). For example, tree removal during construction can decrease canopy cover and the rate of carbon sequestration in the ecosystem. Additionally, "environmental impacts associated with these projects can include loss or damage of riparian forests and export of sediment pulses during construction which may offset project benefits depending on their lifespan" (Palmer et al., 2014). Furthermore, some studies argue that stream restoration projects do not deliver the reductions in TN, TP, and TSS that estimate reductions suggest. In particular, studies have uncovered a "limited capacity for pollutant removal during high flows" (Filoso et al., 2015; Filoso & Palmer, 2011). This uncertainty is exacerbated by a lack of successful maintenance and monitoring programs that provide data regarding annual reductions in TN, TP, and TSS over the short- and long-term. As Thompson et al. argues, referring to the importance of post-stream restoration monitoring, "it is only with adequate data that success can be judged" (2018, p. 8). This lack of consistent data, monitoring, and scientific consensus on the ability of stream restoration to provide long-term improvements to water quality through reductions in TN, TP, and TSS calls into question the investments that local, state, and regional decision makers have made in stream restoration projects.

On the other hand, some experts argue that stream restoration can provide increases to ecosystem services beyond just improvements to water quality. As Sarvillana et al. explains, “conceptualizing ecosystem services is fundamental, as it makes the benefits and useful functions that ecosystems provide more visible, and helps to understand how ecosystems provide both material goods… and non-material services… for human well-being” (2017, p. 10). Below is a list of ecosystem services that have been attributed to healthy, functioning stream ecosystems from an eco-centric perspective (Meyer et al., 2013):

- Groundwater recharge
- Natural flood control
- Drinking water source
- Trapping of excess sediment (preventing siltation of downstream streams and rivers)
- Filtering and processing of nutrients
- Recycling of organic carbon
- Provision of food sources both in the stream and surrounding habitats
- Habitat provision for plant and animal life
- Spawning/nursery area for plant and animal life
- Supporting biodiversity

Additionally, there are many ecosystem services provided by stream restoration that are extremely valuable from an anthropocentric point of view. Groundwater recharge is a product of the connection between the stream and the surrounding riparian area. The water that is stored beneath the surface of the soil is especially valuable in more arid regions where surface water evaporation is a concern. In the event that a stream dries up during the dry season, water can be extracted from the groundwater for irrigation, drinking water, or other human uses (Meyer et al., 2013). Also, natural flood control provides immense value to humans, as climate change threatens existing flood control infrastructure with increased frequency and severity of precipitation events in certain regions. Therefore, the connection of streams with their natural floodplains can protect valuable natural and human infrastructure and reduce the risk of destruction of property (Sarvillana et al., 2017).

Streams that are in healthy, functioning condition also support a wide variety of species, and ideally these species will be native to the region. The presence of these species provides opportunities for recreation (birdwatching, fishing, hiking), research, and/or educational experiences. If these opportunities are available, the local community surrounding the stream restoration area may experience its own revitalization. As is the case with the Little Westham

Creek restoration in connection with the larger Gambles Mill Eco-Corridor project, the stream restoration has prompted the revitalization of the entire surrounding area, integrating stream restoration goals with larger goals of encouraging increased community use and involvement with the site. It is clear from the Gambles Mill Eco-Corridor project designs that some stream restoration projects involve much more than just lowering stream bank height and altering the stream's path; they aim to create harmony between the natural, built, and human environments (see Gambles Mill Eco-Corridor project plan, Image 5). On a city-wide scale, this increased investment and integration of the human and natural environments could include improvements to local parks or other recreational infrastructure, allowing local residents and visitors to more deeply connect with nature (Alahuhta et al., 2013). Although these ecosystem services may be hard to quantify monetarily, they provide value to the community that needs to be considered as part of the equation when holistically evaluating the impact of stream restoration projects.

Conclusion

Based on this research, I have come to the conclusion that cost benefit analysis alone cannot accurately represent the risks and rewards associated with stream restoration, especially in an urban context. By outlining each of the ecosystem services that are a product of stream restoration and connecting them to the cost benefit analysis of pollutant reductions relative to cost, I hope to expand our understanding of the power of stream restoration projects and the potential they contain for improving ecosystem function. Nevertheless, stream restoration projects should be integrated into the natural landscape in accordance with the needs and desires of the local community. Proposing stream restoration projects as a way to gain TMDL credits without asking for input from the community will result in political, social, and economic tension that is counterproductive and unsustainable (as is evident from the backlash in response to the Reedy Creek project). It is clear that understanding stream restoration in a holistic manner is vital in order to ensure that stream restoration projects yield ecosystem service improvements beyond reductions in TN, TP, and TSS, while also meeting the needs of the surrounding community.

In 2019, the DPU announced its intention to complete a stream restoration by 2022 at Pine Camp in the far Northside neighborhood of Richmond. This project presents immense potential, with 2200 linear feet of proposed restoration, 800 pounds of TN, 3700 pounds of TP, and 462,000 pounds of TSS reduction annually (information provided during an RVAH2O update meeting on November 18, 2019 by Grace LeRose of the DPU). Applying the lessons learned from previous and current stream restoration projects, the City of Richmond and the DPU have the opportunity to plan and execute this project with a more integrated focus on the human and natural environment. This stream restoration project has the potential to profoundly impact local water quality, access to recreational and educational opportunities, and improve overall watershed health in the James River and Chesapeake Bay. Improving watershed health on multiple scales within the Chesapeake Bay region will continue to require high levels of coordination and cooperation between residents, government officials, and experts in ecosystem and water quality health. Stream restoration is not the "magic fix" to the more widespread issue of diminished water quality in the Chesapeake Bay region, and recognizing all potential risks, costs, and benefits will allow for a more holistic approach to be applied to the revitalization of our waterways on a regional scale.

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Supporting Images

Image 1: Before (left, taken in 2017, provided by RES) and after (right, taken in 2019, provided by RES) stream restoration photos of Little Westham Creek restoration project (located on University of Richmond property). The lowered and stabilized stream bank allows the stream flow to be more naturally connected with its floodplain. In the case of a heavy precipitation event, the stream can overflow into the floodplain, allowing sediment and nutrients to be deposited into the soils of the floodplain instead of being swept downstream. This also reduces the risk of heavy flooding downstream, as less water flows into the Kanawha Canal, and eventually the James River.

Image 2: Before (left, taken in 2017, provided by RES) and after (right, taken in 2019, provided by RES) stream restoration photos of Little Westham Creek restoration project (located on University of Richmond property). The relatively straight path of the creek was reengineered to flow in a meandering, S-curve in order to slow down the transport of nutrients and sediment. The slower flow rate also reduces the risk of flooding downstream.

Image 3: University of Richmond students collect data in Little Westham Creek pre-restoration (above left, 2017, photo courtesy of RES). The location of Little Westham Creek on University of Richmond property provides opportunities for student and faculty research and community-based learning through invasive species removal and other maintenance projects on site.

Image 4: Students from an Environmental Studies and Geography Senior Seminar class learn about the stream restoration process from experts at RES. There are clear, hands-on learning opportunities that are provided through the stream restoration process and its continued maintenance and monitoring (above right, 2019, photo courtesy of Todd Lookingbill).

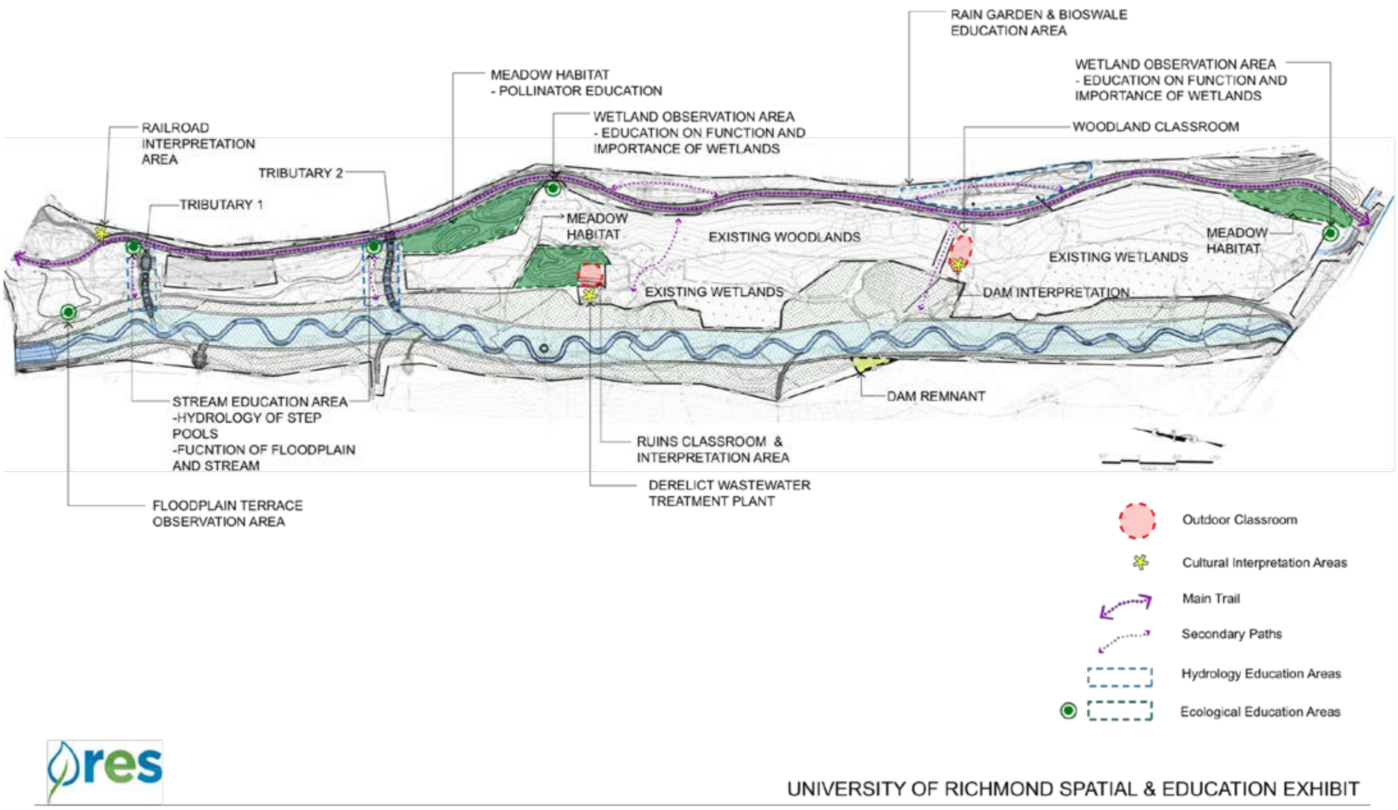

Image 5: Gambles Mill Eco-Corridor Map (provided by RES, 2019). In this plan, there is a clear integration of existing natural and human infrastructure with new features. The walking and biking trail has been revitalized and there are secondary paths that connect the stream and other natural features of interest. Also, personal reflection and classroom spaces have been added for use by students, staff, faculty, and community members. Finally, cultural and historical features uncovered during the restoration process will be highlighted on signage throughout the site.