Stream Restoration as a Method of Improving Local Water Quality

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December 15, 2019

Abstract

Projects of stream restoration are a known Best Management Practice (BMP) to approach stormwater management, and have been adopted globally as a means of improving local hydrology. Urbanization has led to an increase in impervious surfaces, resulting in deteriorated streams, many of which are subject to stream restoration. Stormwater control measures (SCM), such as stream restoration, are considered to be a subset of green infrastructure as a method to reconnect streams with surrounding riparian areas, revitalize original hydrology, and support the local ecosystems. This paper looks into the viability of stream restoration as a way of improving water quality, focusing on Little Westham Creek (LWC) in Richmond, VA. LWC is a tributary into the James River, and part of the greater Chesapeake Bay Watershed. Four metrics were used to analyze the outcome of this restoration: nutrient level measurements, Bank Erosion Hazard Index (BEHI), and fish and benthic macroinvertebrate sampling. The Before-After Control-Impact (BACI) method was used to evaluate data pre- and post-restoration. It was found that concentrations of nutrients may decrease along the reach of the stream, and there is substantial variation in organism populations comparing pre- and post-restoration. It is estimated that the BEHI will produce indices indicating lower risk of erosion post-restoration. While not completely conclusive, these data support the idea that improved water quality is one of many outcomes of stream restoration.

Introduction

Stream restoration is a technique to revitalize streams that have become degraded from their natural state. Stream restoration has grown in popularity as a way to manage stormwater and stabilize stream banks (Kaushal et al. 2008). Since the Clean Water Act of 1972, the nation "has made great efforts in restoring and preserving the physical, chemical, and biological integrity of the nation's waters" (Selvakumar et al.). As urbanization produces more impervious surfaces, the flow and amount of water into waterways has produced flows with greater strength and intensity resulting in more erosion and sedimentation, eventually changing the natural structure and flow of the stream leading to further repercussions.

Urban areas have greater instances of stream degradation as a result of increased impervious surfaces, changes in land use, and disconnection from riparian areas (Johnson et al. 2014, Kaushal et al. 2008). As a result, many stream restoration projects have been in areas with increased urbanization. The aim of many urban stream restoration projects is to reconnect floodplains, decrease sedimentation and bank erosion, and to compensate for the effects of urbanization. One study uses percentage of area of the watershed that is considered to be an impervious surface as an indicator of urbanization, with higher fractions of imperviousness correlating to greater effects of urbanization (Bell et al. 2016). Due to the inherent imperviousness of urban settings, including the roads, neighborhoods, and buildings, there is less open land into which water can soak during precipitation events. This has led to more runoff into nearby waterways, leading to faster and more intense flows of water. With the natural flow of water disturbed, there is less time for nutrients and sediment to settle out of the water, and effects are seen in the quality of the water flowing through and out of waterways.

Stream restoration, a method of stormwater management, is often classified as a type of green infrastructure. Green infrastructure is a term with its use becoming more frequently to describe restoration and stormwater management projects, and "has the potential to catalyze a shift toward a more hydrologically and ecologically functioning system, contributing to a comprehensively more sustainable regime in the integrative sense of sustainable development" (Lieberherr, Green, 2018). By focusing on the function of a water system, such as a stream, it can be observed that many are lacking their natural efficiency and many streams qualify for intervention such as restoration efforts.

The term restoration is widely accepted to include structural changes to streams with the aim to return them to pre-development conditions, increasing functionality. The definition proposed by the US EPA and quoted by Shields et al.: "the return of a degraded ecosystem to a close approximation of its remaining natural potential" (Shields et al., 2003). However, some argue that it is near impossible to reconvert a stream completely, mimicking its natural characteristics. The term rehabilitation or remediation may be more fitting, with each term converting the stream further from the its original characteristics, respectively. Regardless of the category in which the stream is classified, each aims to improve functions of flood control and ecological management (Kidoo, Seong 2019).

As means of stream restoration, some methods incorporated include increased wetland space, a wider, more accessible floodplain, step-pools, bioretention ponds, increased sinuosity, and channel riffles in the reconstructed hydrology. Each of these assets will improve the functionality and promote the natural integrity of the stream. Methods for restoration vary, with other projects including creation of oxbows, and fully redesigned channels; other stormwater management techniques may also include detention ponds, wet ponds, bioretention, and sand filters (Pennino et al. 2015). These features have been shown to uphold during strong rain events, promoting flood patterns that one would see in a healthy, naturally occurring stream.

The reconnection between a waterway and its floodplain will improve stream functionality, with reconnection "refer[ring] to the exchange of water, nutrients, organic matter and biota between streams and floodplains", which is beneficial for the purposes and goals of restoration projects, regarding the efficiency of the stream (Singh et al., 2018**)**. Restoration works to decrease the height of streambanks and increase stream-floodplain connectivity in order to increase the frequency of a stream flooding its banks, allowing for nutrients to settle out during rain events. As the water recedes, the nutrients will settle into the riparian area, both nourishing the land and plants and decreasing the amount of nutrients that flow into the greater watershed.

There is still some uncertainty and speculation as to the true benefits and consequences of stream restoration, and whether or not its implementation should be widespread. Because all the implications resulting from stream restoration have not yet been established, it had been suggested that it should not be considered as a stormwater Best Management Practice (BMP), because it has not yet been fully supported that it is indeed an optimal election for stormwater management (Williams et al. 2017). Additionally, some argue that the ecological disturbances are not worth the benefits gained by restoring the stream (Palmer et al. 2005). Despite these concerns, stream restoration is generally considered to be more beneficial than detrimental, and most projects achieve the goals set for each respective restoration, and stream restoration can be considered a practical way of stormwater management.

The standards set by the Clean Water Act (CWA) have contributed to the implementation for Total Maximum Daily Loads (TMDL), specific to each respective type of nutrients. In order to be in compliance, cities need to decrease the amounts of nutrients that they contribute to specific watersheds. Specific TMDLs were implemented for the Chesapeake Bay in 2010, in order to improve water quality and aid in pollution control (Chesapeake Bay TMDL). The overarching goal of nutrient reduction in LWC that enters the Chesapeake Bay watershed is 1,440 pounds of TP annually, which is achieved through the various mechanisms of stream restoration to be implemented. As part of the Lower James River basin, the TMDL for annual TP set by the US EPA is 141,451 pounds; the impact of the reduction of TP from the LWC restoration would be a 1.02% decrease in TP entering the Chesapeake Bay, assuming that the TMDL is precisely met (Section 9, Chesapeake Bay TMDL, personal calculations). Excess levels of nutrients, such as N and P, have contributed to “the growing impacts of urbanization on watershed nutrient exports have contributed to coastal eutrophication and hypoxia both regionally and globally”, which have had negative effects on the health of the Chesapeake Bay on the East Coast (Pennino et al., 2016).

This project focused on whether the restoration of Little Westham Creek (LWC) has led to a decrease in levels of nutrients that flow out of the stream. Taking into account time and practicality as limitations, I focused solely on LWC, comparing pre- and post-restoration data. A part of the James River Watershed, feeding into the greater Chesapeake Bay watershed, the water and its components that flow out of LWC have an impact on water quality further downstream. With excess nutrients flowing into the other waterbodies, events of eutrophication may occur, resulting in further ecosystem repercussions. Focusing on LWC allowed for local, detailed data, and led to information on its impact on the watersheds in the area. The City of Richmond has an inherent interest in this stream restoration, as it will contribute 2,300 feet of linear stream toward their goal of stream restoration of 2,500 linear feet, as a strategy for stormwater management. As part of their Clean Water Plan (2017), the City aims to restore and protect the waterways in the James River watershed, improving the quality of water which will eventually flow into the Chesapeake Bay.

Methods

Westhampton Lake, which flows into LWC, is considered to be a BMP for stormwater management. As water flows into the Lake from surrounding areas, sediments and nutrients settle to the bottom of the lake as the water then flows toward LWC, resulting in water that has relatively higher quality entering LWC than when it entered the Lake. Additionally, the flow of the water is somewhat controlled as it flows into the Creek, decreasing the amounts of sediment and nutrients flowing from the lake into the creek. In terms of stormwater management, the restoration of LWC has been considered a BMP for the City of Richmond, as it modifies the hydrology of the stream to improve functionality and efficiency. However, stream restoration has not yet been classified as a BMP for stream water quality. Through the methods described below, I hoped to provide insight to support the idea that water quality is directly improved through stream restoration.

The LWC watershed totals 2,100 acres, with 40% of that considered to be impervious (Arch Designs, RES, 2018). With 14% impervious surface as a control in their study, Bell et al. would classify the Gambles Mill Eco-Corridor to be urban due to the relatively high percentage of impervious surface in the area, totaling 840 acres. The watershed includes the University of Richmond, an urban setting due to the residential nature of the adjacent land and the number of buildings and walkways on campus, as well as its setting in the counties of Richmond and Henrico, and proximity to the City of Richmond. Of the floodplain accessible by the stream, 2.2 acre feet of that area is considered to be “available floodplain” during precipitation events; this is the area onto which LWC will overflow (Arch Designs, RES, 2018).

One source of nutrients entering LWC includes runoff from the golf course owned by the Country Club of Virginia, adjacent to the eco-corridor on the east side. Additionally, there is data that shows the contribution of N from Westhampton Lake into the flow of LWC, presumably from residential areas and runoff from the University’s irrigation systems. It has been shown that “nutrients are essential for plant growth, but…. [excess nutrients] can alter the composition and species diversity of the aquatic community”, and nutrient levels should be monitored and regulated to a degree in which the ecosystem is healthy (UR Water Quality Report, 2019). The combination of the various sections of the stream restoration should work in unison to minimize the flow of nutrients, therefore increasing water quality downstream and improving overall ecosystem wellbeing.

In 2006, there was an attempt to revitalize LWC, at a point further up the headwaters. This project was focused on a much smaller scale, with the goal of improving the stream buffer, in order to improve water quality and reduce erosion and sediment transport. Sediment coming from Westhampton Lake and the neighborhoods within the area of the creek were of most concern. In order to do this, native plants were installed on the streambanks, and nearby residents received increased education regarding the creek and how to aid in its upkeep. Another goal of the project was community engagement, in order to increase awareness of the impact of local actions (LWC Web Presentation). In this most recent restoration of LWC, we will not only be planting native species, but non-native species were removed through the process of grazing with goats. This project also differs in that the structure of the stream has been altered, as well as the riparian areas.

Some measures of success of restoration projects include cost-effectiveness, stakeholder satisfaction, aesthetics of the final product, protection of existing infrastructure and historical areas, increased recreation, contribution toward the pool of knowledge of stream restoration, ecological factors (Palmer et al. 2005). This project has focused on the ecological factors and stakeholder satisfaction, with stakeholders including the University of Richmond and the City of Richmond.

I utilized the Before-After Control-Impact (BACI) approach, a technique used to estimate the magnitude of effects on the outcome of a project, and the amount of stress (to the environment) that has resulted by comparing data from before and after the project (Smith 2002). I compared and analyzed pre- and post-restoration data. I incorporated the analysis of four metrics to assess the restoration of LWC: water samples measuring concentrations of nutrients, BEHI index, fish sampling, and benthic macroinvertebrates sampling. At this point in time, weeks after the completion of the restoration, a preliminary post-restoration analysis can be observed.

Water Quality Analysis

Many studies compare restored streams with other natural streams with conditions ranging from forested locations to degraded urban streams, with a range of 4-16 streams included in each study. The studies also focused on areas that have been urbanized, as that is where stream degradation has been most apparent, due to increased impervious surfaces from development (Bell et al. 2015). Many studies that focus on the processes and success of stream restoration have a timeline of at least two years, taking water samples every 2-4 weeks.

In the past, water quality data has been gathered monthly from Westhampton Lake and parts of LWC, as well as recently in the weeks after restoration has been completed. These evaluation techniques consider physical, chemical, and biological indicators of water quality for a wholistic evaluation of the outcomes of this restoration (Selvakumar, et al.). Most analyses of stream water restoration as a stormwater management practice focus on levels of N, studying the capacity of denitrification of newly restored streams, as related to Protocol 2, presented later in this study (Williams et al. 2017). Other goals of restoration may include reduction of annual loads of Total Phosphorus, as well as sedimentation levels as a result of stream bank erosion.

For this project, water samples were taken once toward the conclusion of the project, analyzing and measuring levels of Nitrogen (N) and Phosphorus (P). Samples were taken from four locations along LWC, as seen in Figure 1 below. At each site, the sample vial was rinse three times with water specific to each location. The fourth water collection was kept to be analyzed in the lab, with either the nitrate or phosphorous test kit, with their respective procedures. These measurements were instrumental to this evaluation, and contribute toward determination of whether or not stream restoration should be used as a way to decrease excess nutrients, such as N and P, to get a wholistic picture of the outcome of the restoration.

BEHI Analysis

Another method of analysis included the Bank Erosion Hazard Index (BEHI), which measures the risk of a stream's bank for erosion and resulting sedimentation (Allmanová, Jakubis 2016). Prior to the stream restoration, data was gathered by ArcCollector and used to calculate pre-restoration BEHI statistics, to be used for comparison post-restoration. Comparing LWC's BEHI indices, both pre- and post-restoration, as well as to conventionally accepted BEHI values for "healthy" streams, I can evaluate the success of the restoration in terms of sedimentation, which will also effect TSS values. There are four categories classified by BEHI, characterizing the stream bank as being a very low, low, moderate, high, very high, or extreme risk for erosion.

Pre-restoration methods for measuring BEHI included three protocols to evaluate the potential for efficiency of the stream post-restoration. These protocols are consistent with typical stream restoration project models, and offers a preemptive evaluation of the outcomes of the stream restoration project (Stream Restoration Revisited). The reduction in nutrients and sediment loads contribute toward the TMDLs for the Chesapeake Bay, benefitting the entities which are subject to pollution control reporting.

Protocol 1 focuses on the specific calculations of LWC, including erosion rates, nutrient load totals, and the efficiency of the stream post-restoration. Through a variety of factors and calculators, and two different estimates of stream efficiency (50% and 85%), estimates for sediment input due to erosion and subsequent estimates for nutrient loads were calculated (Arch Designs, RES, 2018. p.19). BEHI is a valuable metric in this step of evaluation as it presents a quantitative valuation of the detrimental effects of streambank erosion.

Protocol 2 calculates denitrification credits as a result of the restoration project. After calculating the final length of the stream post restoration, which comes out to be 2,736 feet of restored stream, calculations were made to estimate denitrification rates post-restoration (Arch Designs, RES, 2018. p.19).

Protocol 3 examines the floodplain reconnection aspect of the project, focusing on the specifics of the watershed and the accessibility of the floodplain during precipitation events. A stream's connection to its floodplain is critical for nutrients to settle out during and following rain events, rather than flowing downstream, at a high flow-rate, as might happen if the stream is degraded. This step investigates the amount of "storage" held by a floodplain, quantified by the size of the watershed and the floodplain storage volume. With capacity of the floodplain known, it is then possible to estimate the annual load reduction rate of nutrients and sediments (Arch Designs, RES, 2018. p.19).

Fish and Macroinvertebrate Sampling

Prior to restoration, RES collected data on fish and benthic macroinvertebrate populations of LWC. The surveys counted the number of fish and recorded each species within a short time period, about twenty minutes. Fish surveying included isolating the area of interest to be sampled, and using an electrofishing unit to attract the fish to be classified and counted (Simpson et al. 2014). For the purpose of this study, I analyzed the data previously collected by RES and did not sample the populations myself. Counting the number of fish and their respective species, I compared species found pre- and post-restoration to evaluate biodiversity of LWC.

Results

Prior to restoration, Nitrogen values averaged 1.162 mg/L, and Phosphorous values averaged 0.077 mg/L, between March of 2018 and June of 2019, as reported from intermittent sampling (Westham Creek Data Monitoring Report, 2019). Samples were taken in late November to document preliminary post-restoration concentrations. Water samples from the four specified sites included nutrient levels are as follows:

	Site A	**Site B**	**Site C**	**Site D**	**Average**
Nitrate (mg/L, NO_3)	2.7	2.0	1.2	1.2	1.78
Phosphorous (mg/L, PO_4)	3.8	2.5	2.1	2.2	2.65

Table 1. Results from water sampling

The BEHI pre-restoration showed that most of the banks sampled were categorized as High or Very High, with some Moderate, and very few Low. The samples were taken at 18 sites along the 2,154 linear feet of stream, both the left and right sides of the stream. Pre-restoration erosion rates of streambanks totaled from left and right banks of LWC were 1,363 tons/year. Phosphorous and Nitrogen loads 1,430.87 lbs/year and 3,107 lbs/year, respectively.

Prior to restoration, LWC supported eleven different species of fish, with 233 fish in total. Post-restoration sampling found six species, with a total of 205 fish surveyed over the course of about 20 minutes. Fish present pre-restoration only were the Pirate Perch, Yellow Bullhead, Tessellated Darter, American eel, Warmouth, Green Sunfish, Pumpkinseed, and one Hybrid Redbreast/Bluegill. Overlap between species pre- and post-restoration included Bluegill, Eastern mosquitofish, and Largemouth Bass; new species found post-restoration only included the Bluntnose Minnow, Spotfin Shiner, and Central Stoneroller (RES).

Benthic macroinvertebrate populations preceding restoration presented a variety of species: aquatic worm, flatworm, leech, sowbug, scud, blackfly, narrowing mayfly, broadwing mayfly, dragonfly, blackfly, dancefly, common netspinning caddisfly, broadshoulder beetle, riffle beetle, non-biting midge, waterpenny, mosquitoes, viviparidae snail, physid snail, Asian clam, and other unclassified invertebrates and beetles. The species were all in larval form (RES).

The post-restoration data on BEHI and macroinvertebrate sampling has not yet been completed, and therefore comparison between pre- and post-restoration conditions is not possible at this time.

Discussion

The analyses of the outcomes of stream restoration are preliminary, as construction concluded weeks ago. According to the architectural plans for this project, "the purpose of this project is to restore Little Westham Creek between Westhampton Road and River Road, and renovate the trail that runs parallel to the stream corridor" (Arch Designs, RES, 2018). The newly renovated Gambles Mill Eco-Corridor on the campus of University of Richmond includes 2,300 feet of linear stream, which has been the focus of the restoration project, highlighting the "hydraulic, geomorphic, physiochemical, and biological properties" in order to decrease sedimentation and flow of nutrients (Arch Designs, RES, 2018). Some of the purposes of this project include the reduction of streambank erosion, as well as decrease the loads of Total Phosphorous entering into the greater Chesapeake Bay watershed. Additional products of this project should include the reduction of nutrient loads of N and P.

Water Quality Analysis

The sampling of N and P in this study showed a decline in nutrient concentrations between site A and site D. The location of samples was purposeful, and the results indicated that the assets throughout the stream may have a positive impact on water quality. Another study found that concentrations of N and P decreased from the inlet to the outlet of the stream, suggesting that the stream was effective in reducing nutrient levels (Thompson et al.). The two sequences of step pools act to slow the flow of water, which results in longer retention time and allows for nutrients to settle out of the water. In conjunction with the increased sinuosity of the stream, the flow of water is slowed, also allowing for nutrients and sediment to precipitate out. The bioretention ponds farther downstream aid in this process as well.

Water quality in LWC has an impact on the greater Chesapeake Bay watershed; it is important with regard to TMDL regulations and overall health of the Bay and its tributaries to improve water quality to its optimal state. Comparing the pre-restoration data collected leading up to construction with the post-restoration data I gathered, it would seem that the restoration has been detrimental to water quality. The nutrient levels gathered pre-restoration were substantially lower than the values I had sampled, which averaged 1.78 mg/L and 2.65 mg/L for N and P, respectively. Variation between samples may be due to a variety of factors. I would rule out seasonal changes, because the original samples were taken periodically throughout the year, regardless of season, although temporal and special variability and flow speed of the stream variability may lead to differences in measurements (Kaushal et al. 2008). Although not addressed in this study, both Carbon in its various forms and Total Suspended Solids (TSS) are additional valuation techniques to analyze water quality.

One study further supports the idea that stream restoration improves water quality, suggesting that streams that are connected to their natural floodplains are more productive, resulting in improved water quality by "minimize[ing] sediment and nutrient loading by taking up and processing nutrients and trapping sediments" (Singh et al.). Note Image 3 below. The stream has an overflow point of 0.1 inches of rain, proving the high connectivity with its floodplain, with the floodplain having 2.2 acre feet of capacity to hold water (RES). Additionally, higher connectivity of a stream with its floodplain, in cooperation with low streambanks, access to wetlands, and increased vegetation in riparian areas have higher rates of denitrification (Johnson et al. 2013). As the riparian buffer continues to grow and the stream goes through flooding phases, water quality should continue to increase.

BEHI Analysis

Soil conditions are pertinent to the success of stream restoration and will impact the long-term viability of the project. If the native soil type is highly erodible, the likelihood of the stream returning to its degraded nature is likely. The soil surrounding LWC is characterized as Chewacla loam/silt loam, with moderate erodibility and moderate to high permeability (Arch Designs, RES, 2018 p. 14). A higher permeability classification suggests that this soil will help with flood control, with water infiltrating the ground rather than flowing directly into the stream. As pointed out by Rosgen, "accelerated streambank erosion is a major cause of non-point source pollution associated with increased sediment supply" (Rosgen 2001). With more stable streambanks, less erosion should occur, therefore decreasing the sediment levels in LWC as well as those downstream.

BEHI levels pre-restoration showed that the majority of areas measured as high or very high regarding risk of erosion. BEHI values are based on various measurements and functions of the stream such as bankheight, bankfull root depth and density, and slope steepness, and the index values of a "healthy" stream should all show low BEHI, indicating that the streambanks are in great condition at this point post-restoration (Rosgen 2001). As time goes on, the values will likely change, showing progression, but should consistently demonstrate acceptable BEHI indices along the length of LWC. Although post-restoration data has not yet been processed, based on the proposed and observable structure and hydrology of LWC after construction, I would expect BEHI levels to have decreased from pre-restoration states (see Images 1-2 below).

In conjunction with BEHI indices, Near Bank Stress (NBS) is based on the velocity gradient of the stream, and is another qualitative analysis tool that works in conjunction with BEHI to indicate risk of erosion and resulting sedimentation (Rosgen 2001). BEHI is based on bank height, bankfull height, rooting depth, and bank angle, to produce a qualitative value to categorize risk of erosion (Allmanová, Jakubis, 2016). BEHI and NBS were both measured in preparation for the restoration project by RES. NBS may be a valuable metric/method in the future, but was not included in the analysis of this project.

Estimates for pre-restoration conditions of total annual load of sediment, for the left and right mainstream banks of LWC totaled 246.7 tons per year. In accordance with the calculations of Protocol 1, pre-restoration loads of P totaled 1,430.89 lbs/year, and 3,107.06 lbs/year of N. Based on these calculations, post-restoration reductions in sediment, P, and N were estimated to be 123.3 tons/year, 715 lbs/year, and 1,554 lbs/year, respectively, if the restored stream flows with 50% efficiency (RES, 2019). These reductions in loads are preliminary estimates, but should contribute toward city credits for TMDLs of nutrients and sediments flowing into the Chesapeake Bay, and are considerable efforts toward an increase in water quality overall.

The Rosgen Stream Classification systems offers a comprehensive framework to group together streams of similar characteristics, based on the BEHI. It takes into account sinuosity, depth of the thalweg, interaction with the streambank, as well as other geomorphological attributes (Watershed Academy Web). Prior to restoration, LWC would have been classified as an F4 stream, evidenced by the incised and entrenched shape of the stream, moderate sinuosity, and steep, eroding banks. Post-restoration, LWC fits within the classification of an E4 stream, and borderline C4, fitting the natural characteristics of streams prior to the industrial era. LWC now exhibits characteristics such as higher sinuosity, more curves, lower banks and increased connection to floodplains, creating wetlands that have a tendency to flood during rain events. (A. S. Lambert, RES). Additionally, the geomorphology of this stream is better suited for aquatic life, with the mix of riffles, pools, and wetlands, supporting more biodiversity.

Fish and Macroinvertebrate Sampling

Comparing fish and benthic macroinvertebrate populations in LWC provided information on water quality, as many species of benthic macroinvertebrates need a specific range of conditions in order to survive and reproduce. There is concern regarding stream restoration that it is more disruptive than it is beneficial, with the process of restoration causing irreparable damage to local ecosystems in adjacent wetland and riparian areas. Many of the species found within LWC pre-restoration were not native to the stream and its habitat, originating in Westhampton Lake and making their way over the dam and into LWC. Benthic macroinvertebrates are indicators of a healthy waterway due to their nature of living in the same area from larval stage through adulthood, and their nature of the habitat in which they thrive (Selvakumar et al.). Benthic macroinvertebrates are categorized as tolerant, somewhat sensitive, and sensitive (Sevin, UR Stream Ecology Lab). Using this ranking system, it is possible to evaluate water quality by identifying which species and number of individuals thriving in the area.

The most recent fish sample and the first after restoration (October 23, 2019) showed lower diversity than pre-restoration. Because of the construction, fish previously inhabiting the stream will have mostly been decimated. It has been suggested that fish inhabiting lakes will present bottom-dwelling characteristics, such as a flatter body shape and a ventral mouth; fish more suited to streams will have longer, narrower bodies, and their mouths may be dorsal or terminal (B. Siegfried, RES). Various fish may make their way from Westhampton Lake into LWC, or may come from downstream, swimming upriver from the James. Initial succession of the stream in the preliminary stages post-restoration will likely vary as time goes on, although the early stages post-restoration should see species known to thrive in streams. It is possible that other fish species may inhabit the stream once again, although they may not thrive given the conditions presented by the newly restored stream.

The Bluntnose Minnow, Central Stoneroller, and Spotfin Shiner were the three species of fish observed post-restoration that were not present in LWC prior to construction. The Bluntnose minnow and the Central Stoneroller are both common in the James River watershed, and known to be found in small, local pockets of the area. Shiners, in general, are a known river-dwelling family of species, along with many other minnow-type fish (Native Fish). These three species were not present prior to the restoration, indicating that they are suited for the area, and I would expect them to thrive in this stream setting going forward. American eels have also been found in many tributaries and rivers that connect with the James. They were present before restoration, and although not found in the most recent survey, I might expect that they would eventually inhabit LWC once again (Freshwater Fishes).

The Eastern mosquitofish was also observed post-restoration. As the name suggests, the mosquitofish feeds on mosquitoes, and given that mosquito larvae were observed pre-restoration, it should not be surprising that both may be present in LWC. Largemouth Bass tend to be common in rivers and ponds, especially “quiet, weedy habitats” (Freshwater Fishes). Although LWC is not yet full of vegetation, natural progression as well as planned planting may produce more vegetative waters. It has been observed that Bluegills and Largemouth Bass are often found together, inhabiting similar areas and waterways (Freshwater Fishes).

Species such as the Warmouth and the Pumpkinseed are characterized as sunfish, like the Bluegill and Largemouth Bass. However, Warmouth are aggressive fish, and Pumpkinseed are not a far-reaching species, suggesting that neither would be optimal to make a home in LWC at any point in time (Freshwater Fishes). All of the species observed in both pre- and post-restoration sampling are native to the James River area, but some are more suited than others to thrive in an environment such as LWC.

Different species have varying levels of toleration of pollution, disturbance, and shifts in water conditions. As such, benthic macroinvertebrates are particularly good indicators of water quality, and have been used in the technique “bio monitoring: a method used to assess the quality of a river or stream by surveying for the presence and abundance of certain organisms" (Sevin, UR Stream Ecology Lab) With the various aspects incorporated into the revised shape of the stream, such as channel riffles and pools, as well as adjacent wetlands and connectivity to floodplains and riparian areas, the habitat is better suited for native aquatic species (A.S. Lambert, RES). A diverse array of fish species could demonstrate that the environment is sufficient for survival, but it could also mean that non-native fish with high tolerance for change or variability in living conditions. More biodiversity demonstrates a thriving ecosystem with interdependent species and populations, as one would expect to see in a healthy stream environment.

It has been shown that there is a correlation between the BEHI of a stream and greater biodiversity, suggesting that “in general, banks that scored low on the BEHI were associated with… a more taxonomically rich and spatially stable macroinvertebrate assemblage”, with low BEHI meaning lower risk, rather than the categorization as “low” (Simpson et al., 2014). The pre-restoration data showed benthic macroinvertebrate species fitting into the “tolerant” category, were all present when the stream was considered to be degraded and the BEHI classifications were “high” and “very high”. I would expect that with improved water quality, biodiversity would increase, and there would exist more species in LWC compared with prior to restoration in LWC. This supports the idea of stream restoration and its effect on stream water quality, as with more stable banks (higher BEHI categorization, lower risk), less erosion occurs and creates a better living environment to support a more diverse ecosystem.

Additionally, the City of Richmond recognizes macroinvertebrate monitoring as a measurement of water quality, as a means of evaluation of pollutant reduction (RVA Clean Water Plan 2017). As a stakeholder in this Clean Water Plan, which aims to improve water quality across the city and downstream, the University of Richmond with LWC on its property represents one of many contributing entities with the goal of improving water quality within the city and in the outstanding watershed.

Levels of erosion risk related to BEHI, biodiversity, and nutrient levels are all indicators of water quality. Conversely, if the BEHI suggests that erosion is still negatively impacting the area, biodiversity plateaus or decreases, or nutrient levels cease to decrease, may be indicators that contradict my hypothesis that restoration is beneficial to water quality. LWC will need to be under continual monitoring over the next several years in order to collect data to determine long-term outcomes of the restoration project. As explained by Kaushal et al., “stream restoration associated with stormwater management that increases hydrologic connectivity can increase denitrification rates”, tying together the purpose of restoration for both stormwater management and water quality purposes (Kaushal et al. 2008).

Conclusion

By reducing the amount of sediment and nutrients carried throughout the corridor, local and downstream water quality is inherently improved. It cannot be absolutely concluded whether or not stream restoration improves water quality. The results from this study present substantial support that improved water quality is one of the outcomes of stream restoration, but further research and evaluation will need to be conducted over the course of the next several years in order to get an accurate and specific representation of the results and effects of stream restoration.

Variation in the stream and riparian areas will affect the water quality as time goes on. Growth of the tree canopy and other aspects of the ecosystem, floods and then recession of the stream, the stream will progress and change and will need to be monitored on a regular basis.

Additionally, natural succession will play a part in which species, both plant and animal, thrive and impact different aspects of the stream. These varying factors, among others, may lead to different results than I have presented in this paper, but should continue to support the idea that the stream has been improved as a result of restoration. Stream restoration is known for its impact on increased functionality, and should also be considered for its positive effects on water quality, including nutrient and sediment loads, and health of local ecosystems.

Storymap link: https://storymaps.arcgis.com/stories/863745201baf444283acbbccc35e5159/edit

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*Special thanks to Todd Lookingbill and Anna Stuart Lambert for their guidance and supportive information throughout this project.

Supporting Figures and Images:

Figure 1 (below, left). Site 1 represents water flowing through LWC from Westhampton Lake. With little time for hydrological components of LWC to filter out any incoming nutrients from the lake, this sample should be an accurate representation of the quality of water as it enters LWC. Site 2 samples water taken right at the step pool, which acts as a buffer for water entering from the golf course. Site 3, samples water taken just after the step pool. Water from Site 4 was taken from farther downstream LWC, representing the water quality after various assets of the stream, before flowing through the bioretention pond and into the greater watershed.

Image 1 (above). LWC pre-restoration shows high, steep streambanks, a wide channel, and although not as visible in this photo, follows a straight path with little variation.

Image 2 (right). Post-restoration, LWC is characterized by thinner channels and much shallower streambanks, and meanders throughout the Eco-Corridor.

Image 3. Showing LWC's new connection to the floodplain, as water spilled its banks after a rain event.

Image 4. A point in the stream with a deeper thalweg leading into a higher flowing point in the stream. The deeper part of the stream will act as a small retention pond, allowing time for nutrients and sediment to precipitate out of the water and settle to the bottom of the stream.