COLLEGE OF ENGINEERING
COLLEGE OF AGRICULTURE AND LIFE SCIENCES
BIOLOGICAL SYSTEMS ENGINEERING

December 6, 2023

W. Cully Hession
Professor of Biological Systems Engineering
200 Seitz Hall
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Dear Dr. Hession,

Enclosed please find an analysis of potential solutions for the project titled "Newton Creek Resiliency Project." This report contains details regarding our proposed treatment train and an examination of various solutions for each respective step. We have included our criteria and decision matrices for each step and a discussion of how these should be incorporated to our final design moving forward, with input provided by Wetlands Watch. An updated Gantt chart team responsibilities for the upcoming spring semester is included. Our advisors, Dr. David Sample and Dr. Venkat Sridhar, have had an opportunity to review this document.

We have neither given nor received unauthorized assistance on this assignment.

Sincerely,

Ellie Buehrer   Gavriel Cambridge   Cyrus Li   Parker Sullivan

Enclosure: Analysis of Potential Solutions

Newton Creek Resiliency Project

Technology Review

BSE 4125: Comprehensive Design Project
October 31, 2023

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Introduction

Coastal cities face a unique combination of threats posed by global climate change. Climate change has increased the intensity and shortened the return periods of storms, and has increased the mean sea level, flooding coastal areas. Sewell Point, a short 25 minute drive from the project site in Norfolk has experienced the worst flooding in the past decade out of 34 sites on both coasts surveyed in a 2023 survey conducted by the EPA (U.S. EPA, 2023a). Sewell Point, similar to Norfolk, is situated adjacent to the Elizabeth River. Various factors can further contribute to flooding in Norfolk, such as the seasonal high tide, called the "King Tide", and more importantly storm surges associated with hurricanes. The combination of tidal and stormwater flooding can easily overwhelm existing stormwater management infrastructure. This report serves to evaluate the potential solutions included in series as components of a "treatment train" designed to address various water quantity and quality issues. This project proposes a sequence of BMPs forming a 4 step treatment train: Conveyance, Storage, Treatment, and Release.

Conveyance. The first step of this treatment train will be conveyance. Water may enter the Best Management Practice (BMP) from a number of sources, and each of these sources must be accounted for. In addition to surface runoff and water conveyed through conduits, tidal water may also enter the system by back flowing through its drainage conduits. This dynamic should be considered as part of the collection step.

Storage. The next step is Storage. The storage area serves to attenuate peak runoff flows by creating additional volume for storm or tidal water to collect and sit. This aspect of the BMP can be multifunctional. For example, it may serve to store water that would otherwise be flooding adjacent infrastructure (parking lots, streets, etc) during a high intensity rain event, but it may also serve as green space for community members to gather and recreate during times of more pleasant weather. Additionally, the storage step may serve to foster habitat for wildlife.

It should be noted here that while each step of the treatment train has the potential to offer many different kinds of benefits, when a single design is ultimately chosen, not every potential benefit will be realized. No design can do everything at once, and so these types of trade-offs are necessary.

Treatment. The treatment step improves stormwater quality by removing pollutants such as excessive sediments, nutrients, and bacteria. The treatment step may also serve multiple purposes similar to the storage step.

The last step of the BMP is Release. This step serves to convey treated water to adjacent bodies of water, in this case the Elizabeth River. If a surface water connection between the river and the BMP is constructed, this step could capture storm surges, facilitate tidal exchange, and even facilitate the transition of the design site into tidal wetland.

Descriptions of Potential Solutions

Conveyance.

There are three possible options for stormwater conveyances. The first of these, concrete drainage channels, can quickly and effectively route stormwater runoff towards storage devices. Channel geometry can either be trapezoidal (sloped sides, excavated in situ) or rectangular (vertical, reinforced walls) (U.S. Army Corps of Engineers, 1995). Construction, materials and labor may incur higher initial capital costs; however, maintenance costs are considerably lower due to the durability, longevity, and availability of concrete. Aside from the repair of damaged concrete, periodic inspections and the removal of clogging debris is typically sufficient. Nevertheless, a major downside to concrete channels is that they are impermeable surfaces. As such they offer little in the way of flow resistance, resulting in a greater peak discharge and potentially unsuitable rates of flow into the storage stage.

An alternative to concrete gutters are vegetated grass-lined channels, which serve the similar purpose of concentrating stormwater runoff and decreasing flooding in critical areas. Unlike concrete-lined stormwater channels, grass-lined channels are permeable surfaces which can reduce peak discharge, provide velocity control, and offer some capacity to filter sediments following storm events. Cross-sectional geometry can be triangular, trapezoidal, or parabolic, though flatter side slopes are required compared to concrete channels due to the increased risk of soil erosion (U.S. EPA, 2021). Grass channels are especially susceptible to erosion when runoff velocities are high; accordingly, the maximum design velocity is heavily influenced by the onsite soil characteristics. Maintenance is more intensive during the channel's inception with inspections occuring after each storm event. This involves identifying erosion, removing sediment, and potential channel inlet stabilization (VDEQ, 2011). Once vegetation has fully established maintenance needs begin to relax, with annual inspections and regular mowing becoming standard procedure.

Rock-lined swales, also referred to as dry creek beds, are likewise permeable and work in a similar fashion to grass-lined channels. As its name suggests, these BMPs- often aided by the use of rounded stones- imitate the aesthetic of natural creek beds. They are usually more erosion-resistant than their fully-vegetated counterparts, as the large rocks hold underlying soil in place despite higher flow velocities. However, these same rocks tend to make construction and maintenance more costly by comparison. Deposited sediment will engulf rocks over time if the bed is not cleared regularly, and resurfacing sunken rocks can be an arduous process. Monthly inspections are necessary along with repairs to dislodged rocks and eroded soil (Tahoe BMP, 2014).

Storage.

Four potential storage solutions are evaluated in this report: un-lined retention ponds, lined retention ponds, dry detention ponds, and underground storage. Retention ponds are excavated depressional areas meant to store water. They typically always contain some water, but are designed to provide additional storage during storm events. Two forms of retention ponds are considered for this stage: unlined and lined ponds. Unlined ponds rely on slow draining or compacted soils, and position in the landscape to store surface water. Lined retention ponds employ an impermeable liner made of plastic, rubber or concrete to separate a volume of water stored in the pond from the water table. This is particularly important in areas with higher water tables, preventing the expression of the elevated water table and allowing for treatment of stored water before it is lost to groundwater exchange. Dry detention ponds provide storage during rain events or storm surges, but otherwise remain dry. They are usually wide shallow basins that allow for other uses such as sports fields or parks, that are not hampered by occasional flooding when they are not in use. Finally, underground storage solutions employ empty below ground volumes that fill with excess surface water input through either a conduit or infiltration. These usually work best in areas with lower water tables and offer site specific storage usually for buildings or smaller areas of impervious surfaces.

Treatment.

Two options are being assessed for the treatment of stormwater following the storage stage: Constructed wetlands and swales. Constructed wetlands use modifications to topology and soils to form wetland habitat that facilitates the growth of obligate and facultative wetland plant species that perform ecosystem services such as the uptake of excess nutrients and sediments suspended in stormwater. The vegetation and microbial communities that establish in wetlands can continuously treat water as it is stored in the wetland. This treated water is then pushed through the system as fresh stormwater and tidal inputs reach the wetland. These wetlands work well in close proximity to wet retention ponds, and have the potential to provide habitat for many native plants and animals in a relatively habitat limited environment.

Swales typically work well in upland environments that allow for the separation of the water table from the bottom of the swale. Swales are in essence drainage areas similar to a vegetated channel that serve to simultaneously treat and convey stormwater. For this report, swales have been separated from vegetated channels in order to focus more on the treatment capacity rather than the conveyance potential. Two forms of swales are to be considered, wet swales and dry swales. Wet swales are designed to form wetland conditions in the base of the swale, and often have a stored volume of water in the swale. Dry swales use infiltration in the base of the swale through a designed soil media to reduce runoff flows. These largely rely on separation from the groundwater table in drive infiltration and treatment and thus do not perform well in areas with a high water table.

In both swale types treatment largely occurs only during storm events, treating runoff as it routed around a site. Although this is a useful way of providing additional treatment, it does not perform as well as a constructed wetland serving as the primary means of treatment (Ekka et. al., 2021). The primary limitation in the use of wet swales as the main form of treatment is in the cross sectional area required to maintain the dual functionality that make wet swales useful. To increase the treatment potential the swale cross sectional area should be maximized, but this reduces the transport capacity of the swale.

Release.

This report considers three possibilities for conveying treated water into the Elizabeth River: constructing a surface channel, utilizing existing stormwater pipes, or installing new culverts. A daylighted surface connection to the river is critical to the absorption of storm surges as they move inland, and to the exchange of nutrients and water with tidal fluxes. Surface channels require significant modifications to the infrastructure surrounding the site, such as train tracks, highway bridges, and roads. Piping into the existing stormwater network requires less modification to existing infrastructure, but requires accurate design of storage and release systems so as to avoid exceeding the capacity of the storm sewer network. Additionally, the storm water network, Culverts underpassing existing infrastructure would also require significant modifications to the area around the site, but less than a daylighted surface connection while still providing some of the benefits of bi-directional flow.

Define and Weigh Criteria:

Criteria	Definition	Weight
Functionality	Attenuation of stormwater and storm surge peaks. Improvement of key water quality parameters	0.3
Design Life and Adaptability	How long the design will function even under increasing salinity and inundation	0.25
Cost	Total cost of initial design	0.2
Maintenance	Cost and Ease of Maintenance	0.1
Aesthetics	Appearance and integration into existing surroundings.	0.1
Habitat	Ability to provide habitat for native wildlife.	0.05

Ranking Scale:

Rank	0	1	2	3
Description	Does not meet criteria	Somewhat meets criteria	Mostly meets criteria	Fully meets criteria

Discussion of Results

From the conveyance channels assessed, concrete channels have the smoothest surface and therefore the lowest flow resistance whereas river rock lined channels have the roughest surface and therefore the highest flow resistance. Vegetated channels fall between concrete and river rock when it comes to roughness. Because of this, river rock lined channels will be most effective in slowing down peak flow (VDOT, 2017). When it comes to cost, concrete channels are the most expensive and vegetated channels are the cheapest (GeoSolutions, 2023). However, concrete channels provide little aesthetics and no habitat. With this in mind, the three solutions were ranked based on our criteria and the river rock channel ranked the highest. Using a river rock channel for conveyance will provide the highest attenuation of stormwater flow, habitat and aesthetics.

For the storage solutions, the main options are retention or detention ponds. Although in ground storage was considered, this option will not provide stormwater attenuation or improve water quality. In ground storage is also much less feasible in this area due to high water tables. Retention ponds have a significantly higher nitrogen and bacteria removal rate than dry detention ponds (VDEQ, 2013). Retention ponds also provide much more aesthetics to an area as well habitat. When considering lining a retention pond, although it adds to the cost it also helps prevent bank erosion, seepage, and contamination (BTL, 2023). The cost of lining a retention pond is not significant, and the benefits outweigh it. Based on this information, a lined retention pond was ranked the highest of the proposed storage solutions.

The treatment methods proposed were a constructed wetland, a wet swale, and a dry swale. Water quality swales are designed for the purpose of treating water rather than conveying, and they remove pollutants at much higher rates than other vegetated drainage channels. The main difference between the wet and dry swales is that dry swales have an underdrain system (DEEP, 2004). Although dry swales have higher removal rates of metals and nitrate than wet swales, a dry swale would be less effective in our site due to high water tables (U.S. DOT, 2023). Constructed wetlands have higher pollutant removal than swales and require less maintenance

(U.S. EPA, 2023b). Additionally, constructed wetlands provide more habitat and aesthetics. Because of this, constructed wetlands were found to be the best option for the treatment step.

Lastly, with respect to the release stage of the BMP, three options were primarily considered. Those options were to construct a surface channel, install new culverts underground, or utilize existing stormwater infrastructure to drain the treatment section of the BMP. In terms of functionality, both constructing new culverts or building a surface channel were given the maximum score. This is because these structures can be designed to convey projected flows. In other words, impacts of climate change can be anticipated and incorporated into the design of these structures (VDOT, 2017). Existing stormwater infrastructure, on the other hand, is obviously already built, and may fail when faced with increased flows and shortened return periods. The next criteria that was considered was design life and adaptability. A surface channel was determined to have the longest design life and greatest adaptability because of its unique ability to utilize natural geomorphological processes. For example, in response to increased flows, a surface channel can widen and deepen, thus increasing its conveyance capacity. On the other hand, if sediment accumulates at a certain point in the channel, new vegetation may take root at this point, thus strengthening the channel in response (Rosgen, 2011). New culverts and existing stormwater infrastructure are equally unadaptable, but new culverts were deemed to have a longer design life simply because they will be less degraded at the start of the designs life cycle than existing stormwater infrastructure. As far as cost, both a surface channel and installing new culverts would require extensive excavation, while using existing stormwater infrastructure would not. These options were graded on this criteria accordingly. As far as maintenance goes, culverts, either existing or newly installed, required minimal maintenance. Essentially, the inlets of such structures should be examined in the Fall when flows are at their lowest point, debris should be cleared when 50% of the flow area is obstructed (USDOT, 2016). A surface channel is much more difficult to maintain because this feature may accumulate debris laterally instead of at a single point like a culvert. Moreover, a primary benefit of a surface channel is its aesthetic value. To maintain this aesthetic value requires more effort than an underground culvert, which is out of sight. Lastly, a surface channel is capable of supporting at the very least a minimal amount of habitat while an underground culvert of either type cannot.

Conveyance Method	Concrete Channel	Vegetated Channel	**River Rock Channel**	
Total Score	1.4	2	**2.3**	
Storage Method	**Lined Retention**	Unlined Retention	Dry Detention	In Ground Storage
Total Score	**2.7**	2.25	1.95	1.05
Treatment Method	**Constructed Wetland**	Wet Swale	Dry Swale	
Total Score	**2.6**	2.25	1.2	
Release Method	**Surface channel**	Existing stormwater infrastructure	New Culvert	
Total Score	**2.6**	1.25	1.8	

Table 3. Summary and Results of Decision Matrices

Conclusion

After analyzing a range of potential solutions for each of the four steps included within the treatment train, the most appropriate BMPs were selected accordingly based on the criteria highlighted and the respective decision matrices. River rock channels were chosen for treatment due to their effectiveness as slowing peak flow velocity and their aesthetic value. Lined retention ponds were chosen over unlined retention ponds and other BMPs for storage due to its higher pollutant removal rate, but also the ability to prevent bank erosion, seepage, and further contamination of stormwater runoff. Constructed wetlands were selected for the treatment stage for maintenance, habitat, aesthetics, and pollutant removal capacity when compared to swales. Finally, for the release mechanism, surface channels are most suitable thanks to their long service life and adaptability.

A trait possessed by many BMPs, including those analyzed in this report, is multi-functionality. Oftentimes singular BMPs are designed around the ability to perform more than one of the aforementioned treatment train stages. A good example of this is with swales, which are also commonly used for conveyance purposes, and possess a limited capacity for storage. When designing a new system in an area with limited land and constraints on multiple sides by transportation infrastructure, it is important to consider how these BMPs can be used to maximize these traits in conjunction with one another, while also allowing for usable green space accessible to the public.

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Appendix I - Weighted Design Matrices

Conveyance:

		Concrete Drainage Channel		Vegetated Drainage Channel		River Rock Lined Channels	
Criteria	Weight	Rank	Product	Rank	Product	Rank	Product
Functionality	0.3	1	0.3	2	0.6	3	0.9
Design Life and Adaptability	0.25	2	0.5	1	0.25	2	0.5
Cost	0.2	1	0.2	3	0.6	2	0.4
Maintenance	0.1	3	0.3	2	0.2	1	0.1
Aesthetics	0.1	1	0.1	2	0.2	3	0.3
Habitat	0.05	0	0	3	0.15	2	0.1
Total			1.4		2		2.3

Storage:

		Lined Retention		Unlined Retention		Dry Detention		In Ground Storage	
Criteria	Weight	Rank	Product	Rank	Product	Rank	Product	Rank	Product
Functionality	0.3	3	0.9	2	0.6	1	0.3	0	0
Design Life and Adaptability	0.25	3	0.75	2	0.5	2	0.5	1	0.25
Cost	0.2	2	0.4	2	0.4	3	0.6	1	0.2
Maintenance	0.1	2	0.2	3	0.3	3	0.3	3	0.3
Aesthetics	0.1	3	0.3	3	0.3	2	0.2	3	0.3
Habitat	0.05	3	0.15	3	0.15	1	0.05	0	0
Total			2.7		2.25		1.95		1.05

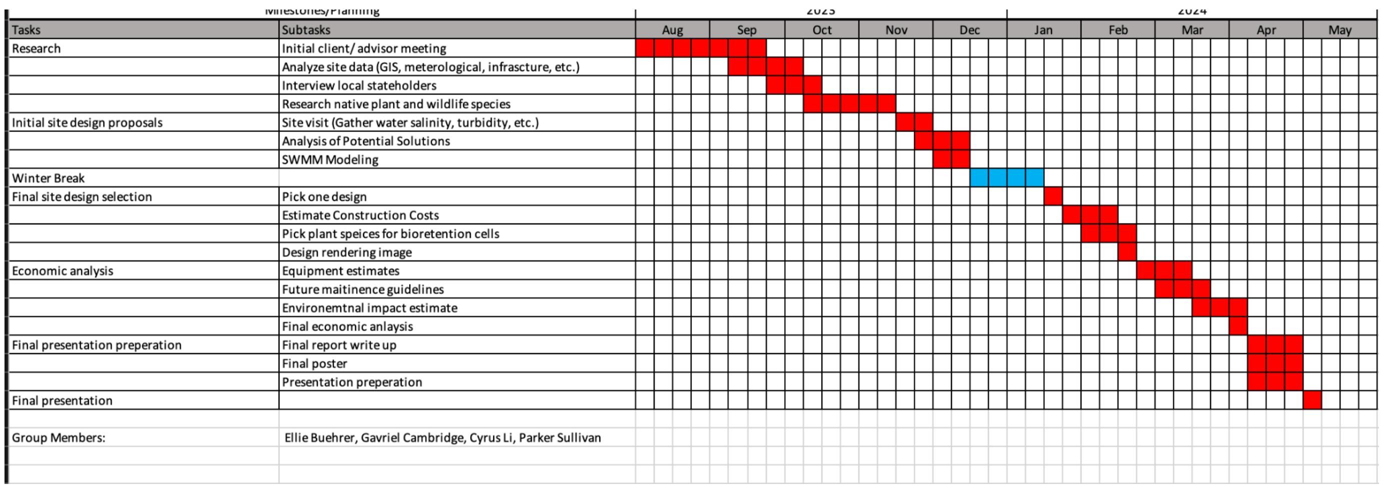
Treatment:

		Constructed Wetland		Wet Swale		Dry Swale	
Criteria	Weight	Rank	Product	Rank	Product	Rank	Product
Functionality	0.3	3	0.9	2	0.6	1	0.3
Design Life and Adaptability	0.25	3	0.75	3	0.75	1	0.25
Cost	0.2	1	0.2	2	0.4	2	0.4
Maintenance	0.1	3	0.3	2	0.2	1	0.1
Aesthetics	0.1	3	0.3	2	0.2	1	0.1
Habitat	0.05	3	0.15	2	0.1	1	0.05
Total			2.6		2.25		1.2

Release:

		Surface channel		Existing stormwater infrastructure		New culvert	
Criteria	Weight	Rank	Product	Rank	Product	Rank	Product
Functionality	0.3	3	0.9	1	0.3	3	0.9
Design Life and Adaptability	0.25	3	0.75	1	0.25	2	0.5
Cost	0.2	1	0.2	3	0.6	1	0.2
Maintenance	0.1	1	0.1	3	0.3	3	0.3
Aesthetics	0.1	3	0.3	0	0	0	0
Habitat	0.05	3	0.15	0	0	0	0
Total			2.4		1.45		1.9

Gantt Chart:


Tasks
Subtasks
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Research
Initial client/ advisor meeting
Analyze site data (GIS, meterological, infrascture, etc.)
Interview local stateholders
Research native plant and wildlife species
Initial site design proposals
Site visit (Gather water salinity, turbidity, etc.)
Analysis of Potential Solutions
SWMM Modeling
Winter Break
Final site design selection
Pick one design
Estimate Construction Costs
Pick plant speices for bioretention cells
Design rendering image
Economic analysis
Equipment estimates
Future maitinence guidelines
Environemtnal impact estimate
Final economic anlaysis
Final presentation preperation
Final report write up
Final poster
Presentation preperation
Final presentation
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