Meadow Creek Golf Course 17th Hole Fairway Erosion and Drainage

A Technical Report submitted to the Department of Civil Engineering

Presented to the Faculty of the School of Engineering and Applied Science

University of Virginia • Charlottesville, Virginia

In Partial Fulfillment of the Requirements for the Degree

Bachelor of Science, School of Engineering

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On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

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Problem Statement:

The Meadow Creek Golf Course, located in Charlottesville, Virginia, is facing ongoing stormwater management drainage, erosion, and sediment control issues. On the 17th hole, ongoing enlargement of a head cut is expanding onto the hole's playing area. The current drainage infrastructure, including upstream ponds and channels, is inadequate, leading to sedimentation, flooding, and water quality issues. The ponds, basins, and streams present in this area cannot effectively treat or handle stormwater runoff. This is causing the golf course to flood, carrying runoff with nutrients from course fertilizers into the Rivanna River. This has broader implications for the Chesapeake Bay, as there are limitations on the amount of sediment, nitrogen, and phosphorus that can be discharged into the bay. The existing stormwater infrastructure is not designed to manage these issues effectively, leading to overland bypass worsening the erosion and sediment problems. The Rivanna River rises above its banks during heavy storm events, and the flooded fairway drains out through the head cut

Statement of Project Scope:

In order to mitigate the Meadow Creek Golf Course stormwater management concerns, some initial action items are identified below. The duration of the project requires the following work to be completed.

- Conduct preliminary desktop and field investigations to confirm drainage pathways and site conditions.
- Perform a watershed assessment and hydrologic/hydraulic (H&H) modeling.
    - Identify sources of pollution.
    - Assess sediment quality in places with visible erosion.
    - Produce a location map with ArcGIS.
- Analyze alternatives for cost-effective stormwater and erosion control practices.
- Create a feasibility report outlining potential solutions, including:
    - Site considerations and potential utility conflicts.
    - Conceptual layouts of best management practices (BMP's) that includes:
        - Hardened outfall with head cut remediation
        - Swale construction
        - New pipe installation
        - Step pool conveyance system (SPCS)
        - Demolition of the original pipe
        - Pedestrian bridge integration
    - Preliminary performance assessments for water quality and quantity improvements

- Construction, maintenance considerations, and permitting needs.
- Estimated conceptual costs and recommendations for next steps.

- Develop schematic design drawings and accompanying technical specifications.
  - Design drawings will be produced through AutoCAD and will highlight the design of the BMP's, along with the corresponding locations, elevations, and specifications.
  - Drawings will include plan and profile views of the proposed solution.
- Create an updated cost estimate and draft a Basis of Design report.
- Address permitting concerns and finalize schematic design packages for client review.

Project Schedule:

The project schedule (see Appendix A) is broken into three categories: site research, feasibility analysis, and design development. Each phase will provide a more detailed understanding of the site conditions and the associated project challenges. This will include multiple site visits to take pictures and collect water samples. Preliminary research will also be conducted during this phase with regard to possible design solutions. The site research phase will run from the beginning of September until the middle of December. The designs presented will include a feasibility report, along with the necessary construction processes. Utility and permitting needs will be identified and preliminary conceptual design layouts will be developed, including initial cost estimates. Finally, a final design package during the design development phase will be produced. Drawings, specifications, cost estimates, and permits will be generated and pulled together for the final design package. This phase will run from the middle of January through the middle of May. Additionally, the head cut was surveyed and elevations were gathered at points in and around it, compiling these points to create an accurate topographic map in Civil 3D. Utility conflict analysis was researched and will be discussed further below. The conceptual designs and the construction feasibility have been worked on and are developed for each alternative solution assessed.

Site Characterization

To track the progression of erosion at the site, a series of photographs seen in *Figures 1, 2,* and *3* were taken at the head cut. These images document changes in the head cut's size, sediment displacement, and the extent of soil destabilization over time. *Figure 4* details measurements taken at the head cut.

Figure 1: First look at head cut on September 23, 2024

Figure 2: Second look at head cut on October 1, 2024 after an extreme storm event

Figure 3: Status of head cut from November 26, 2024

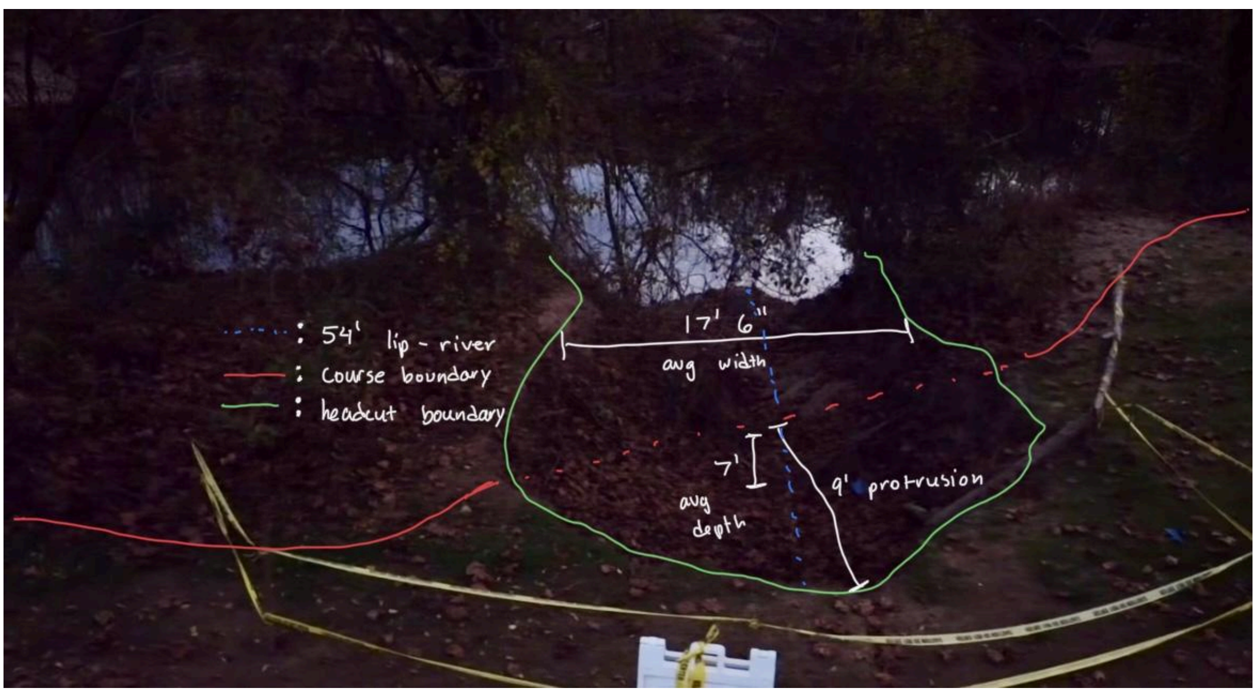


Figure 4: Headcut Measurements

Figure 5: Extreme Flooding From Rivanna

Figure 6: Looking Down At Flooded Fairway

A site assessment was conducted to evaluate existing conditions and constraints at the project location. The advancing erosion observed since the project's inception indicates that the current drainage system is failing to manage stormwater effectively. A camera inspection of the underground stormwater pipe seen in *Figure 7* revealed a blockage, suggesting a potential collapse downstream of the inlet. Despite extensive searching along the riverbank, the outlet of the pipe could not be located, further supporting the likelihood of structural damage. The nearby ponds may require modifications to better accommodate stormwater flow and improve overall site hydrology.

Figure 7: Footage of Blockage Within Existing Pipe

The site has been studied with environmental tests as well. Water quality has been assessed through measurements of phosphate and nitrate concentrations, and total suspended solids tests; the results of which can be seen below in *Table 1*, with a map of the locations shown in Appendix B. Nitrate testing couldn't be done at locations 3 and 6 due to a shortage of testing vials. Nitrate and phosphate levels exceeding 3 mg/L and 0.025 mg/L, respectively, can be indicative of pollution from nutrient-rich fertilizers or other sources (Penn State Extension). Testing indicates phosphorus levels exceed this, but more testing will be necessary to confirm this. Data for total suspended solids testing testing can be seen in screenshots from the excel spreadsheet in Appendix D, which show the pipe inlet and river/head cut locations have the greatest concentrations of sediment by a large margin. The data gathered with these tests support the need for remediation, along with the implementation of an effective stormwater BMP that addresses sediment and nutrient pollution. These results will continue to dictate brainstorming for the best possible solution.

Table 1: Nutrient and Sediment Testing Results

Location	Nitrate (NO3-N mg/L)	Phosphate (mg PO4-P/L)	TSS Concentration based on volume measurements (mg/L)
1 – Near River	1.760	0.300	1209.97
2 – First Closest Pond	0.846	0.106	23.77
3 – Pipe Inlet	X	0.236	187.62
4 – Foamy Spot Upstream	1.040	0.052	12.24
5 – Second Closest Pond	1.010	2.790	17.39
6 – Third Closest Pond	X	0.037	0.79

The National Cooperative Soil Survey (NCSS) Web Soil Survey was utilized to generate a detailed soil map and classification table (see *Figure 8* and *Table 2*) for further site characterization. This tool provided spatially referenced soil data, allowing for the identification of key soil types, their distribution, and associated hydrologic properties within the project area.

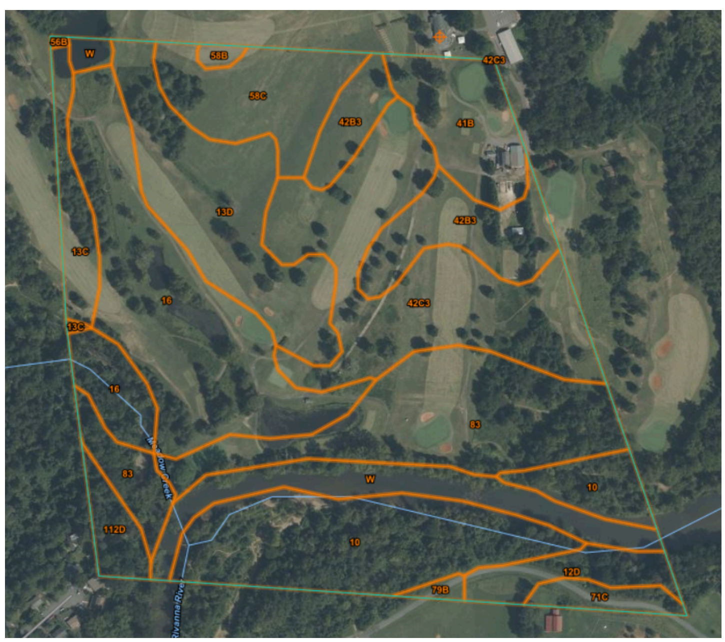


Figure 8: Soil Map

Table 2: Soil Classification

Map Unit Symbol	Map Unit Name	Acres in AOI	Percent of AOI
10	Ronda loamy sand, 0 to 2 percent slopes, frequently flooded	9.2	13.2%
12D	Catoctin silt loam, 15 to 25 percent slopes	1.8	2.5%
13C	Catoctin silt loam, 7 to 15 percent slopes, very stony	1.7	2.5%
13D	Catoctin silt loam, 15 to 25 percent slopes, very stony	7.0	10.0%
16	Codorus silt loam, 0 to 2 percent slopes, occasionally flooded	9.9	14.3%
41B	Yadkin loam, 2 to 7 percent slopes	3.4	4.9%
42B3	Yadkin clay loam, 2 to 7 percent slopes, severely eroded	4.6	6.6%
42C3	Yadkin clay loam, 7 to 15 percent slopes, severely eroded	10.1	14.4%
56B	Meadowville loam, 2 to 7 percent slopes	0.0	0.1%
58B	Myersville silt loam, 2 to 7 percent slopes	0.2	0.3%
58C	Myersville silt loam, 7 to 15 percent slopes	4.0	5.8%
71C	Rabun clay loam, 7 to 15 percent slopes	1.0	1.4%
79B	Meadowville silt loam, 2 to 7 percent slopes	0.3	0.4%
83	Colvard fine sandy loam, 0 to 2 percent slopes, occasionally flooded	8.0	11.5%
W	Water	4.3	6.1%

Subtotals For Soil Survey Area: 65.4 Acres ; 93.9%

To understand the hydrology at the head cut, the watershed was delineated at the head cut using ArcGIS. Using instructions described in Appendix E, the watershed was successfully delineated, and the necessary data for the project was obtained. Included is a layer that had the Charlottesville stormwater pipe network to analyze where water in Pen Park might flow. The analysis aimed to determine whether runoff from the neighborhood within Pen Park would flow directly into a stormwater system or if it would reach the head cut directly. This analysis helped better understand the flow patterns contributing to the head cut, and informs the design for the step pool conveyance system. The boundary of the final delineation can be seen in *Figure 9*, which highlights the watershed area of close to 131 acres and flow paths generated.

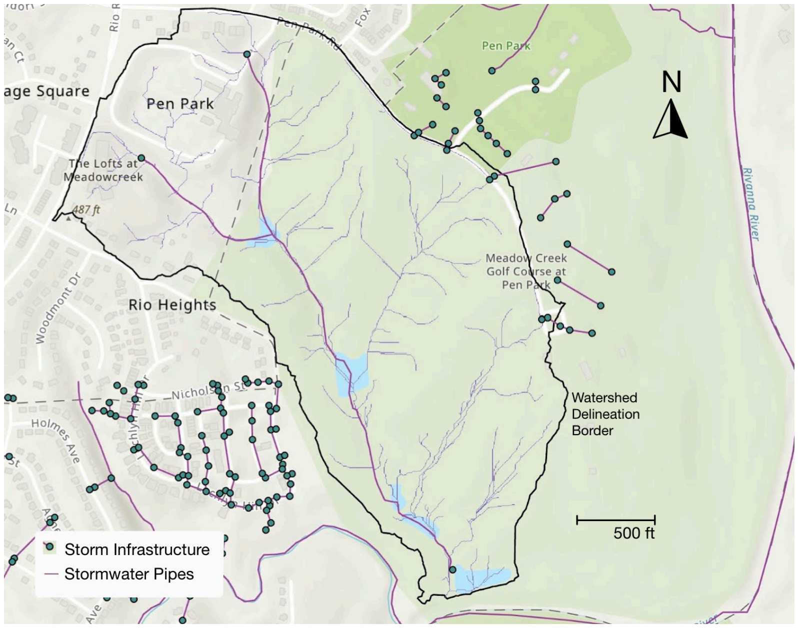


Figure 9: Watershed Delineation in ArcGIS

A close look at the head cut in *Figure 10* reveals in greater detail the surrounding area, and highlights the head cut's proximity to the Rivanna River and where the existing pipe inlet is located. The final design would be implemented in this area, and would span across where the previous pipe started to the Rivanna River. Several subcatchments have been drafted using the previous ArcGIS watershed data as well as the topography of the site. SWMM will portray a conservative model as the geometry of the detention ponds is not known.

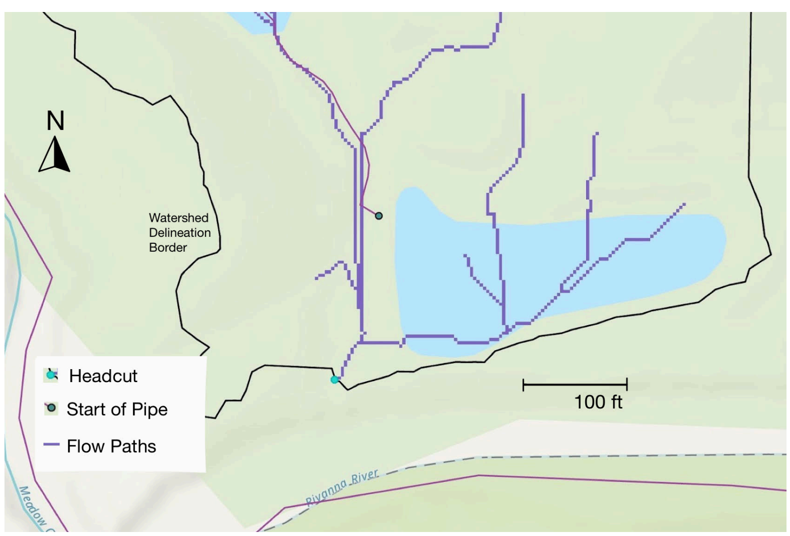


Figure 10: Headcut in ArcGIS

Further surveying of the land was conducted and found the data for the elevations in and around the head cut seen in *Figure 11*. By integrating this survey data into the topographic map of the entire golf course there could be a better understanding of the process of water flow. This survey also allows the erosion to be tracked as it progresses, and the head cut goes deeper into the surrounding fairway. Feasibility studies were created on the ability to construct a new conveyance system seen in *Figure 12* and *13* and analyzed the paths and locations for materials. With this, there is a greater understanding and real life viewing of how to properly stabilize the head cut as well as use equipment to make the new conveyance system.

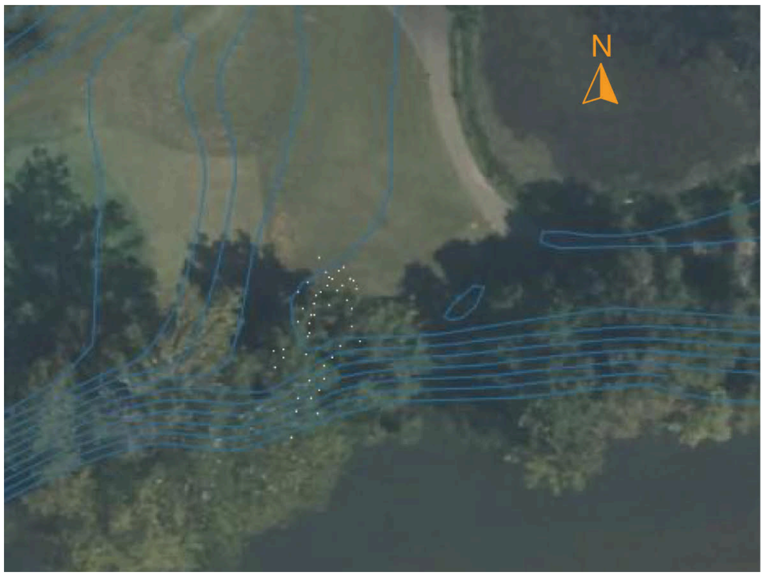


Figure 11: Headcut Survey Data with existing contours

Figure 12: Construction Feasibility Mockup – Heavy Machinery

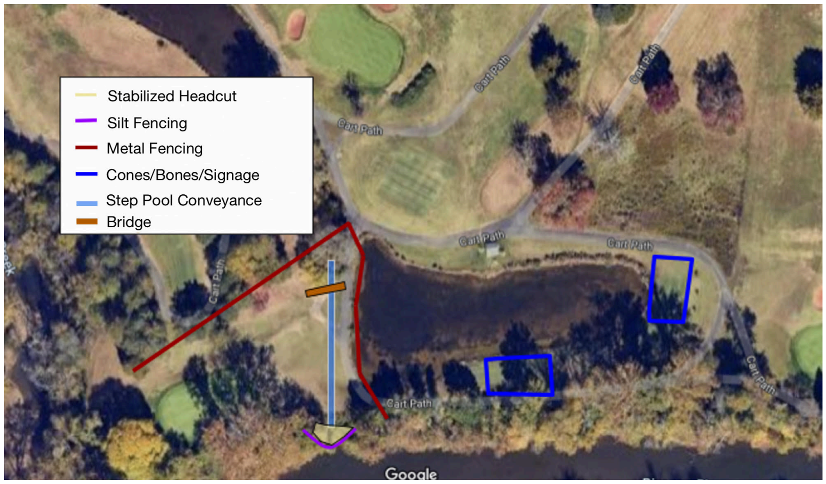


Figure 13: Construction Feasibility Mockup – Spatial Plan

As a part of the surveying process, several flags were found as seen in *Figure 14* marking irrigation and gas lines in the area of the head cut, where the final design is supposed to be implemented. These pose a significant challenge to any excavation and construction in their vicinity. More information is required as to exact locations, but the issues presented by the lines will be further investigated throughout the design and construction process.

Figure 14: Flags showing utilities near head cut and across stormwater conveyance

Hydraulic modeling was also conducted to better understand the peak inflows that the solution would have to accommodate. This was done using three different methods to gain a more holistic view of the watershed: the TR-55 method, the Rational method, and SWMM. *Table 3* displays the peak flows at the pipe inlet using all of these methods for the 2-year, 5-year, 10-year, and 100-year storms.

Table 3: Peak Flows at Pipe Inlet Across Methods

Method	2-year storm (cfs)	5-year storm (cfs)	10-year storm (cfs)	100-yr storm (cfs)
TR-55	25.519	55.609	88.005	260
Rational	43.777	55.117	64.900	123
SWMM	62.979	107.056	144.687	168.945

To maintain consistency, the TR-55 10-year storm value was chosen as the peak flow to design for, as it was the median value of the 10-year storm results. Despite differences in the results, all of the peak flows generated across methods were of similar enough magnitudes to typically create only marginal differences in design requirements.

Proposed Solutions

Multiple solutions are being considered to address the head cut concerns at Meadow Creek, including a new pipe installation with a hardened outfall, a swale, and a step pool conveyance system. Regardless of the final solution, demolition of the original pipe will have to be included along with some sort of remediation of the head cut. As part of the remediation, all of the solutions will include an outfall design that addresses the flows at the head cut. If a swale or step pool conveyance system is chosen, a pedestrian bridge will also have to be designed so that guests at the golf course can access the 17th hole. Each alternative will be assessed based on feasibility, performance, cost, and permitting requirements to determine the most effective solution.

Attached in Appendix F is an example of a step pool conveyance system that will resemble the design for one of the proposed solutions. Design standards will be in accordance with the Chesapeake bay protocol for stream restoration, specifically adhering to protocol 1. This will be used to gain points for the stream restoration and use these points for funding for the project from the Stormwater Local Assistance Fund (SLAF), which was considered for funding due to its assistance in implementing best management practices (BMPs) and can be awarded if there are pollutant removal benefits (Stormwater Local Assistance Fund). Permitting must also adhere to 9VAC25-870-112 of the Virginia Stormwater Management Program (VSMP) Permit Regulations to gain these funds, and the Virginia Stormwater Management handbook itself will also provide more detailed design constraints and recommendations. Protocol 1 is in relation to mitigation of sediment, and states that the following steps must be completed in the design to earn credits: estimate stream sediment erosion rates and annual sediment loadings, adjust project length to account for hard armoring practices, convert erosion rates to nitrogen and phosphorus loadings, and estimate reduction attributed to restoration.

Step Pool Storm Conveyance System Design

The dimensions for the Step Pool Storm Conveyance System (SPSC) were determined in accordance with the *Design Guidelines for Step Pool Stormwater Conveyance (SPSC) Systems* (Flores et al., 2022) published by the Anne Arundel County Department of Public Works. To accommodate the 7-ft head-cut over the 180-ft reach (≈ 3.9 % slope), the design incorporates two cascade weirs followed by a riffle weir, with intervening pools proportioned to maintain hydraulic stability. The detailed sizing calculations appear in Appendix J, and *Table 4* details each component of the system in order.

Table 4: SPSC Design Components

Component	Length (ft)	Elevation Drop (ft)	Parabolic Depth (ft)	Width (ft)
Pool 1	36.67	-	3	10
Cascade Weir 1	30	3	1.5	10
Pool 2	36.67	-	3	10
Cascade Weir 2	30	3	1.5	10
Pool 3	36.67	-	3	10
Riffle Weir 1	10	1	1.5	10
Total	**180 ft**	**7 ft**		

The initial design process began with the export of three primary GIS layers from ArcGIS Pro: contour lines, the delineated watershed boundary at the pipe inlet (start of design), and the delineated watershed boundary at the head cut (end of design). These layers were exported as DXF files to ensure compatibility with AutoCAD. Once imported into AutoCAD, the contour lines provided an elevation reference across the site, while the watershed boundary defined the contributing drainage area and referenced where the design should be located. These layers were used to inform alignment decisions and visualize changes in topography across the project area. With the terrain and watershed data integrated into AutoCAD, the SPSC was laid out to follow the existing drainage path, which can be seen in *Figure 15*. Pools were drawn using ellipses, with weirs drawn in rectangles and with hatching.

Figure 15: Preliminary SPSC Design

After completing the layout in AutoCAD, the design elements were exported as DXF and re-imported into ArcGIS. Within ArcGIS, a centerline was digitized to follow the SPSC alignment using the "Create Features" tool. Cross-section locations were also marked at relevant locations along the centerline to represent areas of hydraulic transition of design significance. The centerline and cross-section cut lines were exported from ArcGIS as shapefiles and imported into HEC-RAS 6.5 using RAS Mapper. The existing terrain data (DEM) was used to create a terrain layer in RAS Mapper, and all features were spatially aligned using the correct coordinate system. A new geometry file was created, and the SPSC centerline and cross-section cut lines were added. These features formed the basis for subsequent hydraulic modeling.

Twelve cross-sections were created along the SPSC alignment to capture changes in geometry and elevation throughout the system, with an example of one being demonstrated in *Figure 16*. Each section was shaped to reflect the intended parabolic form of the pools and weirs. Bank stations and channel geometry were defined for each cross-section to accurately model flow paths. The plan view of the SPSC design can be seen in *Figure 17*.

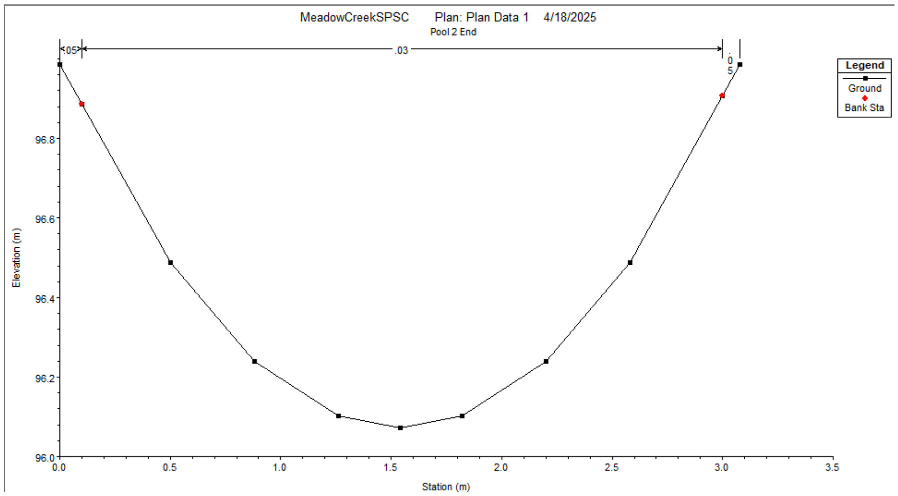


Figure 16: Cross-Section

Figure 17: SPSC Design Plan View

The steady flow analysis in HEC-RAS was run using a supercritical flow regime to best represent the expected hydraulic conditions of the step pool conveyance system. The design incorporates steep cascade weirs and relatively shallow pools, which promote fast, plunging flow between structures rather than slow, backwater-driven conditions. Running the model as subcritical or mixed flow resulted in unrealistic water surface profiles and overtopping, indicating that supercritical flow is the most appropriate choice for accurately simulating the system's intended performance.

Figures 18 and 19 show the 3D and profile views (respectively) of the system under steady flow conditions for various return periods (2-, 5-, 10-, and 100-year storm events). The results demonstrate clear drop structures and confined water surfaces within the designed channel, supporting the validity of the supercritical assumption. The profile view also illustrates the appropriate energy grade lines and water surface elevations for each return period. For the 2-, 5-, and 10-year storms, the water remains confined within the pools, with no overtopping of the banks observed in either the profile or cross-sectional views, with the exception of the 100-year storm event.

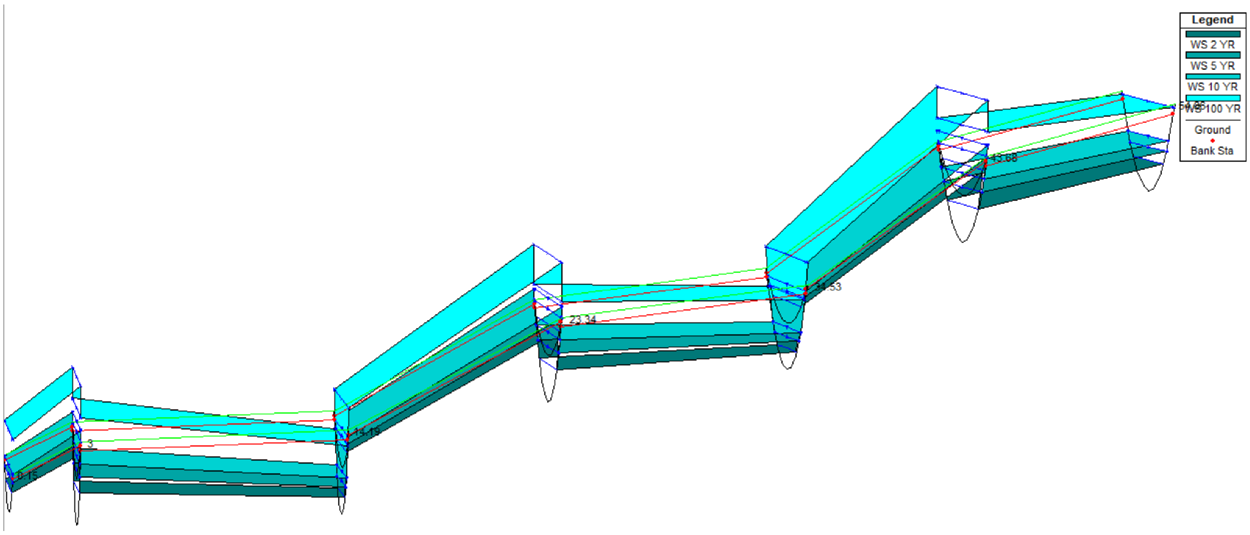


Figure 18: SPSC 3D View in HEC-RAS

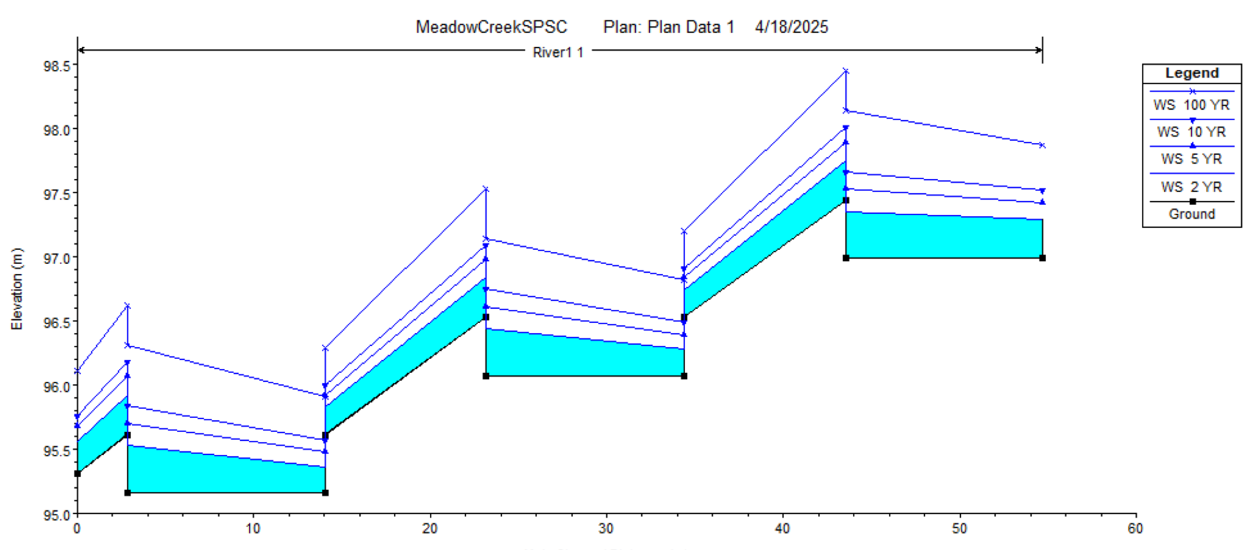


Figure 19: SPSC Profile View in HEC-RAS

The velocity profile (see *Figure 20*) indicates that each drop structure successfully reduces flow velocity locally, with water speeding up at each weir crest and slowing in the pools below. However, the overall velocity from the start to end of the SPSC does not significantly decline, particularly under larger storm events. This suggests that while the system effectively dissipates energy in steps, high-energy flows are maintained throughout the reach, and additional downstream protection may be needed.

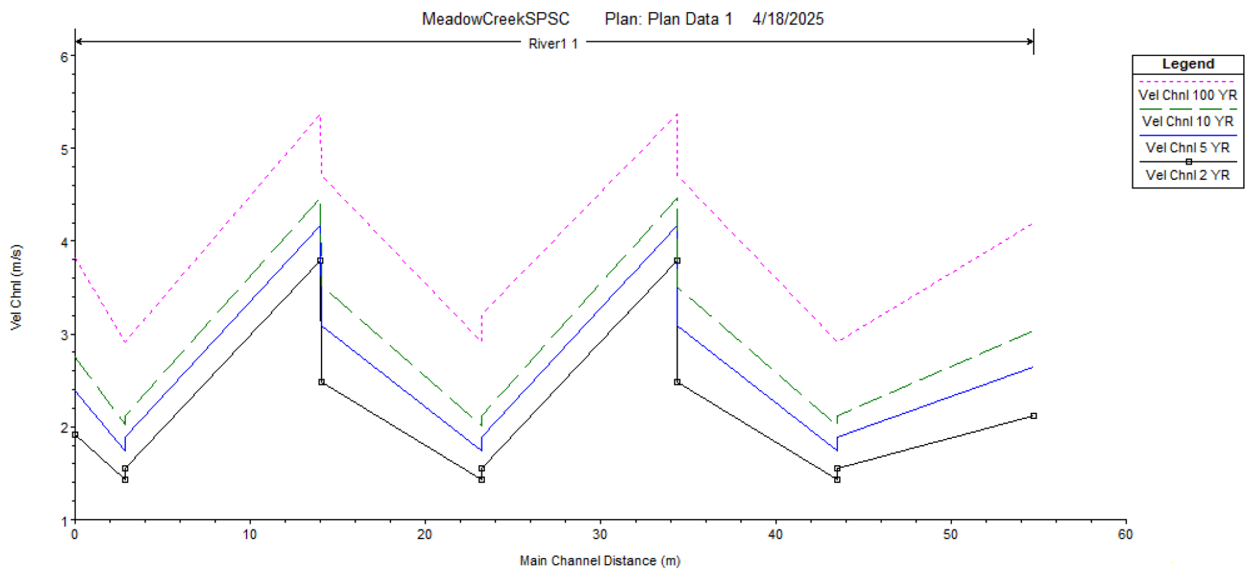


Figure 20: SPSC Velocity Distribution in HEC-RAS

Pipe Design

The new pipe installation is another alternative being considered to SPSC. Using the peak discharge value of 88 cfs, the desired area of the pipe was calculated using Manning's equation. The slope of the pipe and the pipe material for Manning's n were used along with this value to determine the desired area for the pipe after manipulating the equation, which resulted in a pipe diameter of 40". To align with more standard pipe sizes, a replacement pipe size of 42" will be used. The combination of this model and calculations aligns well with what current design features of Meadow Creek include; the existing pipe is 36" in diameter and has led to failure for unknown reasons, one of which could potentially be attributed to undersizing. Sizing up the pipe may offer an effective alternative to the existing one.

Various materials are being considered for the replacement pipe, including reinforced concrete and high-density polyethylene – both had the same range of Manning's n and therefore would not affect the calculations of pipe diameter according to Manning's equation. The cost of each installation would be similar, with RCP costing around 10% more, and both offer strong durability, though RCP can often withstand greater forces and may be appropriate for accommodating such a large watershed area.

Figure 21 shows schematic drawings of plan view layout of where the pipe is to be installed, and *Figure 22* shows the profile view of the starting and end elevations of the pipe. It is to be noted that the location of the existing pipe is not documented under Meadow Creek's records, so exact coordinates cannot be included in the design; the replacement pipe will be implemented where the existing pipe is removed to save excavation costs and time, so the schematic will not be directly followed in terms of aerial view location due to a lack of existing data.

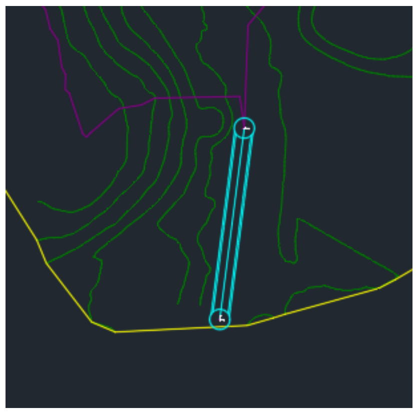


Figure 21: Plan View of Pipe Replacement

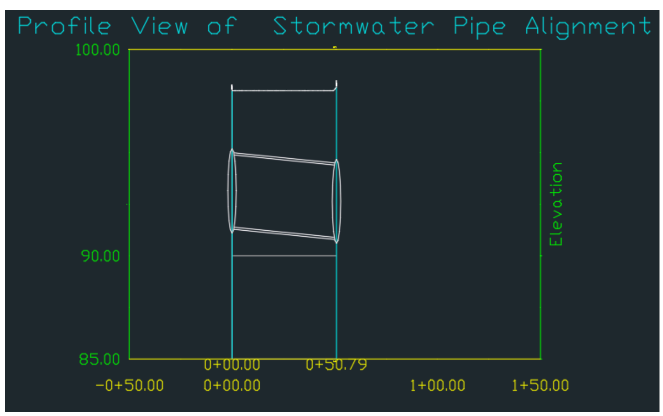


Figure 22: Profile View of Pipe Replacement

Swale Design

The proposed dry swale design follows the same 180' span as the SPSC, with the same 7' elevation drop from inlet to outlet. The plan view is shown in *Figure 23.* In accordance with commonly accepted swale design methodology, the swale will have a trapezoidal cross-section: 15' width, 18" depth, and a 3 to 1 side slope (*Figure 24*). It is important to note that dry swales are generally employed when the average slope is under 2%, so the 3.89% slope is a point of concern for this design alternative. To allow for successful swale implementation at this site, break dams can be added to the design, or the span can be extended, with the inlet being moved farther up the drainage path. Break dams can be implemented to make swales that have up to 6% slope feasible. It is important that the slope issue is addressed in this case to ensure proper construction of a swale.

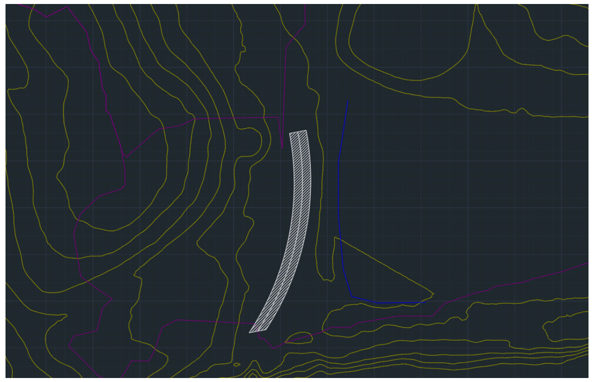


Figure 23: Swale Design Plan View

The swale will follow the existing natural drainage path, same as the SPSC. Unlike the SPSC, the swale will have the same cross-section along its whole span (*Figure 24*). As a result, only the inlet and outlet cross-sections were considered in the steady flow analysis. HEC RAS steady flow analysis showed that the proposed swale design can handle the two, five, and ten year storm events, but not the 100 year event (*Figure 25*).

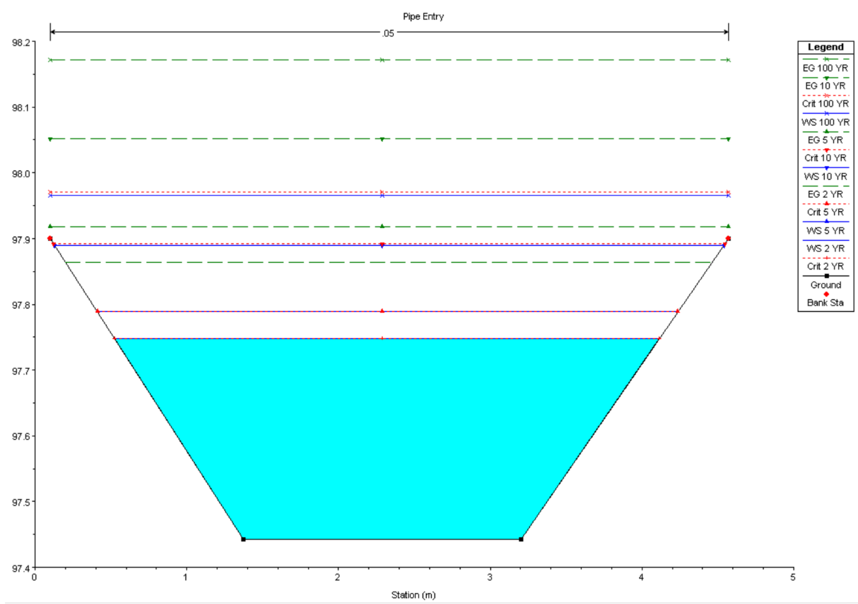


Figure 24: Swale Design Cross-Section

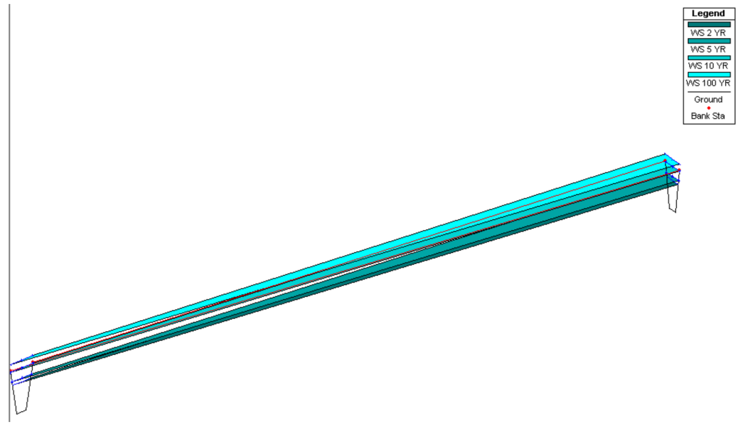


Figure 25: Swale Design Steady Flow Analysis

Design Results

From the preceding information, the three proposed solutions include a dry swale, a step pool conveyance system, and a replacement of the existing pipe with a RCP or HDPE Pipe. In Appendix H, the estimates for the costs for each of these solutions are presented. In all cases, the existing pipe must be excavated, but for the swale and step pool solutions, a pedestrian bridge must be installed to allow players to reach the green. This pedestrian bridge design is shown in Appendix I. A decision matrix is presented below to briefly summarize positives and negatives of each design.

Decision Matrix

Solution	Benefits	Drawbacks
Dry Swale $81,725	- Enhances natural aesthetics - Efficiently manages stormwater - Most cost-effective - Reduces pollutants like phosphorus in the runoff water - Cheapest option - Designed to handle flows of a 10 year storm	- Most extensive of the solutions - Potential for sediment and debris accumulation - Requires pedestrian bridge install (included in price here) - Slope issue
Step Pool System $101,725	- Mitigates water quality and quantity the best - Reduces peak flow velocities - Helps reduce phosphorus and other runoff elements the best out of any solution - Most interesting visually - Designed to handle flows of a 10 year storm	- Cost and construction feasibility - Requires pedestrian bridge install (included in price here)
Pipe Replacement HDPE: $133,390 RCP: $122,715	- Most simple and space-saving solution - Underground solution that preserves existing landscape - HDPE Pipe is lighter than RCP allowing easier install, but requiring more bedding beneath pipe - Sized to handle flows of a 10 year storm	- Potential risk for similar issue in the future - Maintenance difficult inside pipe - HDPE pipe more fragile and susceptible to stress cracking

Comments From Industry:

Don Schrager – Stormwater Utility Administrator

- Replacing pipe would be easiest solution, long lasting solution
- Replacing pipe doesn’t address water quality unless retention area added up or downstream
- Extending the pipe past the planed stabilization/hardening of the bank could lessen the chances of future erosion
- Swale would be simple to construct, but may be maintained similar to the rest of the fairway, therefore subject to fertilizers and chemicals
- Possibility of players going in swale/driving through it and damaging it
- Not many downsides to step pool system

- Possibly could extend rock formation past top of banks to buffer mowing and chemicals

Will Bassett – Management Specialist II, Business/Golf

- Interested in the swale option for feasibility and providing a new hazard and amenity for the 17th hole
- Visual aesthetic of water and bridge would be appreciated, also increasing difficulty of hole
- Providing a new look while also functioning for drainage is important

Philip Seay - Management Specialist II, Golf, PGA Associate

- Swale option preferred as a cut out of "general area" in front of hole 17
- This can create a defined penalty area, providing options under the rules of golf
- The appearance of an island/peninsula-like green is preferred
- A "bail-out area" is already in place to the right of the green
- Something to look into is that several French drains were placed under the #2 fairway emptying into the first retaining pond, 20ish or more years ago

Dan Frisbee - Water Resources Specialist

- Gas flags are likely not marking natural gas lines
- Underground fiber is only utility in area
- Further evaluation will be needed to determine if Option 2 (swale) or 3 (SPCS) would qualify as stream restoration under the Chesapeake Bay Program (CBP) Expert Panel Report since the existing stream is piped
- It may generate more pollutant reduction to consider the project a stormwater outfall restoration (Protocol 5). This practice is subject to a different Expert Panel Report and set of protocols for pollutant reduction accounting
- The ideal solution will convey base flow and storm flows of the stream across the 17 th hole and down to the Rivanna River in a non-erosive manner
- The backwater effects of the Rivanna River during flood events should be considered
- Playability and aesthetics are of the utmost importance. The selected solution must allow for continued (and ideally improved) playability while providing an agreeable look and feel
- Cost is an important factor, the solution that provides the most advantageous pollutant reduction accounting and cost effectiveness (ideally less than $50,000 per pound of phosphorus reduction) will best position the project for grant funding from the Stormwater Local Assistance Fund (SLAF)
- A combination of Options 2 and 3 may be needed. A swale-like feature across the 17 th fairway and then a step pool system down to the Rivanna could be an interesting option

Team Assessment and Decision

The comments made by the industry experts and stakeholders have been considered, and the main points that we want to ensure when choosing a solution are that it is functional in draining water from the creek across the 17th hole, it is aesthetically pleasing and provides a unique feature to the course, the solution reduces sediment and phosphorus loads, and that the solution is cost effective for both installation and upkeep. Based on these considerations and the designs of the solutions, what we recommend is the step pool conveyance system with further consideration of the possibility of creating a combination swale with a step pool system down to the river. The step pool solution is effective in creating an interesting new hazard for players on the hole, would perform best at decreasing the nutrient and sediment load into the river, and would be cost effective to construct and maintain. It would be able to handle the large storm events effectively, and perform properly at draining the creek and flooding situations when they occur.

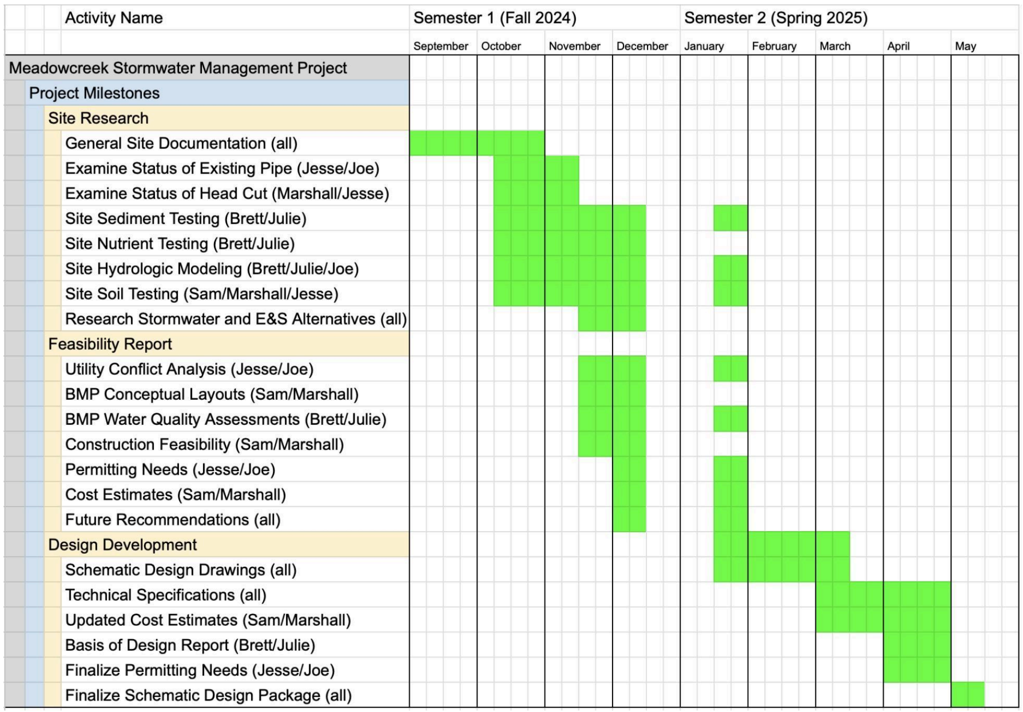
Design Constraints:

There are two primary regulations guiding the design process. The first is the Virginia Erosion and Stormwater Management Act (VESMA), which requires the Virginia Department of Environmental Quality to permit, regulate, and control Virginia soil erosion and stormwater runoff. This would prevent the unreasonable degradation of properties, stream channels, water, and other natural resources. The second is the Virginia Erosion and Stormwater Management Regulation. This regulation provides flexibility for innovative solutions to erosion control and stormwater management issues. Structural integrity considerations involve designing hardened outfalls, swales, pipes, and step pool conveyance systems to withstand extreme weather events while ensuring stable head cut remediation. Utility conflicts require identifying and avoiding existing irrigation and gas lines during excavation, along with coordinating with the city for utility mapping.

Regulatory constraints include compliance with the Chesapeake Bay Protocol for sediment mitigation, adherence to Virginia's Erosion and Stormwater Management Act (VESMA) and Stormwater Management Program (VSMP) permit regulations. Compliance with these regulations aids in pollutant load reductions that meet Chesapeake Bay Total Maximum Daily Load (TMDL) requirements for nitrogen and phosphorus. Additionally, Environmental Protection Agency (EPA) standards must be met by minimizing soil disturbance and preserving natural buffers to enhance stormwater infiltration. Logistical constraints involve limited site accessibility due to the project's proximity to the Rivanna River and golf course playing areas. The permitting process entails securing approvals from the City of Charlottesville, ensuring compliance with regulations. Industry codes, environmental laws, and safety standards provide further guidance. American Society of Civil Engineers (ASCE) and Virginia DEQ standards dictate best management practices for stormwater management.

Appendices:

Appendix A: Detailed Schedule



Appendix B: Water Testing Locations

Appendix C: Engineering Standards Compliance:

Within the Virginia Stormwater Management Handbook, there are certain requirements to be met for different types of stormwater conveyance systems. One of such requirements is with the dry swale, where the bottom of the swale must be 1 foot above the high groundwater level. Also, according to P-CNV-02-2, dry swales should be constructed on slopes of less than 4%, but preferably less than 2%. This same table also mentions that dry swales should only have a drainage area of 5 acres maximum, unless other factors apply. A strict erosion and sediment control plan is required for this project as well because developments are not only responsible for runoff generated on their site, but also responsible for collecting and conveying any runoff entering their site from a neighbor (see 9VAC25-875-560). According to C-ENV-02-1 in the Stormwater Handbook, there are important characteristics to employ within Structural Streambank Stabilization Design Criteria. For instance, gabions, deflectors, and log cribbing are suggested for stabilizing an eroded and rebuilding riverbanks.

During construction, silt fences will be utilized to combat the issues of runoff and erosion throughout the process. The specific standards are taken from the Environmental Protection Agency (EPA) to integrate this technique into the construction phase. 9VAC25-875-500, Stormwater Pollution Prevention Plan identifies the following requirements:

- Control stormwater volume and velocity within the site to minimize soil erosion.
- Minimize the amount of soil exposed during construction activity.
- Minimize the disturbance of steep slopes.
- Provide and maintain natural buffers around surface waters, direct stormwater to vegetated areas to increase sediment removal, and maximize stormwater infiltration, unless not feasible.
- Minimize soil compaction and, unless infeasible, preserve topsoil.

Appendix D: Water Quality Results and Watersheds

Sample Site	Sample Date	Sample Time		Tray Number	Tray & Dry filter (g)	Sample & container (g)	Empty Container (g)	Measured filtered water volume (ml)	(just in case column) tray, filter, sediment pre-oven	Tray & filter & sediment (g)
Third Closest Pond	10/1/2024	15:47		56	1.4134	258.24	6.38	254	1.8564	1.4136
Foamy Upstream	10/1/2024	15:32		37	1.4139	767.91	13.02	760	1.8475	1.4232
Closest Pond	10/1/2024	15:25		W	1.4124	698.05	12.92	690	1.7884	1.4264
Closest Pond	10/1/2024	15:25		11?	1.4131	x	x	x	1.8738	1.4155
Second Closest	10/1/2024	15:41		85	1.4138	447.58	335.1	92	1.8688	1.4154
Pipe Inlet	10/1/2024	15:28		Z	1.4251	479.99	384.1	97	1.8672	1.4433
River/Headcut	10/1/2024	15:20		73	1.4089	431.82	376.65	57	1.9166	1.4779

Sample Site	Sediment (mg)	Sample Mass (g)	Water Mass (g)	Calculated Water Volume (ml)	Sediment Volume (ml)	Cal. Volume of Water & Sediment (L)	Filtrate est. of Water & Sediment (L)	Conc based on mass measurements (mg/L)	Conc based on volume measurements (mg/L)
Third Closest Pond	0.2000	251.8600	251.8598	252.1119119	7.55E-05	0.252111987	0.254000075	0.79	0.79
Foamy Upstream	9.3000	754.8900	754.8807	755.6363363	0.003509	0.755639846	0.760003509	12.31	12.24
Closest Pond	16.4000	685.1300	685.1136	685.7993994	0.006189	0.685805588	0.690006189	23.91	23.77
Closest Pond	2.4000	#VALUE!	#VALUE!	#VALUE!	0.000906	#VALUE!	#VALUE!	#VALUE!	#VALUE!
Second Closest	1.6000	112.4800	112.4784	112.590991	0.000604	0.112591595	0.092000604	14.21	17.39
Pipe Inlet	18.2000	95.8900	95.8718	95.96776777	0.006868	0.095974636	0.097006868	189.63	187.62
River/Headcut	69.0000	55.1700	55.1010	55.15615616	0.026038	0.055182194	0.057026038	1250.40	1209.97

Appendix E: Watershed Delineation Process

The first attempt at delineating the watershed at the head cut in ArcGIS was unsuccessful, as it relied on instructions from the *Water Resources Engineering Workshop (CE 3222)* course. The methodology used in that course did not produce the desired results for this project. A second attempt proved successful by following detailed instructions provided by Esri, which describe how to create a watershed model using the Hydrology toolset in ArcGIS Pro.

A critical step in the delineation process was creating a point feature to represent the pour point of the watershed. This step was guided by another set of Esri instructions on how to create points on a map. These resources were used to delineate the watershed effectively and obtain accurate data for further analysis.

Environmental Systems Research Institute (Esri). (n.d.). *How to create a watershed model using Hydrology in ArcGIS Pro*. Retrieved from https://support.esri.com/en-us/knowledge-base/how-to-create-a-watershed-model-using-hydrology-in-arcg-000023169

Environmental Systems Research Institute (Esri). (n.d.). *Create points on a map*. Retrieved from https://pro.arcgis.com/en/pro-app/get-started/create-points-on-a-map.htm

Appendix F: Example of Previous Designs and Deliverables

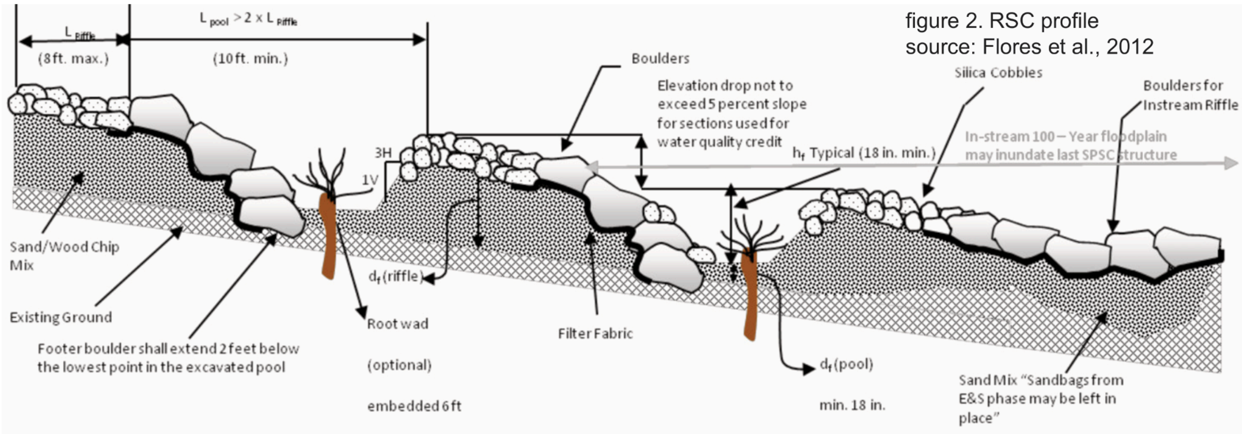


Figure 26: Regenerative Step Pool Conveyance System Example (Gregg et al.)

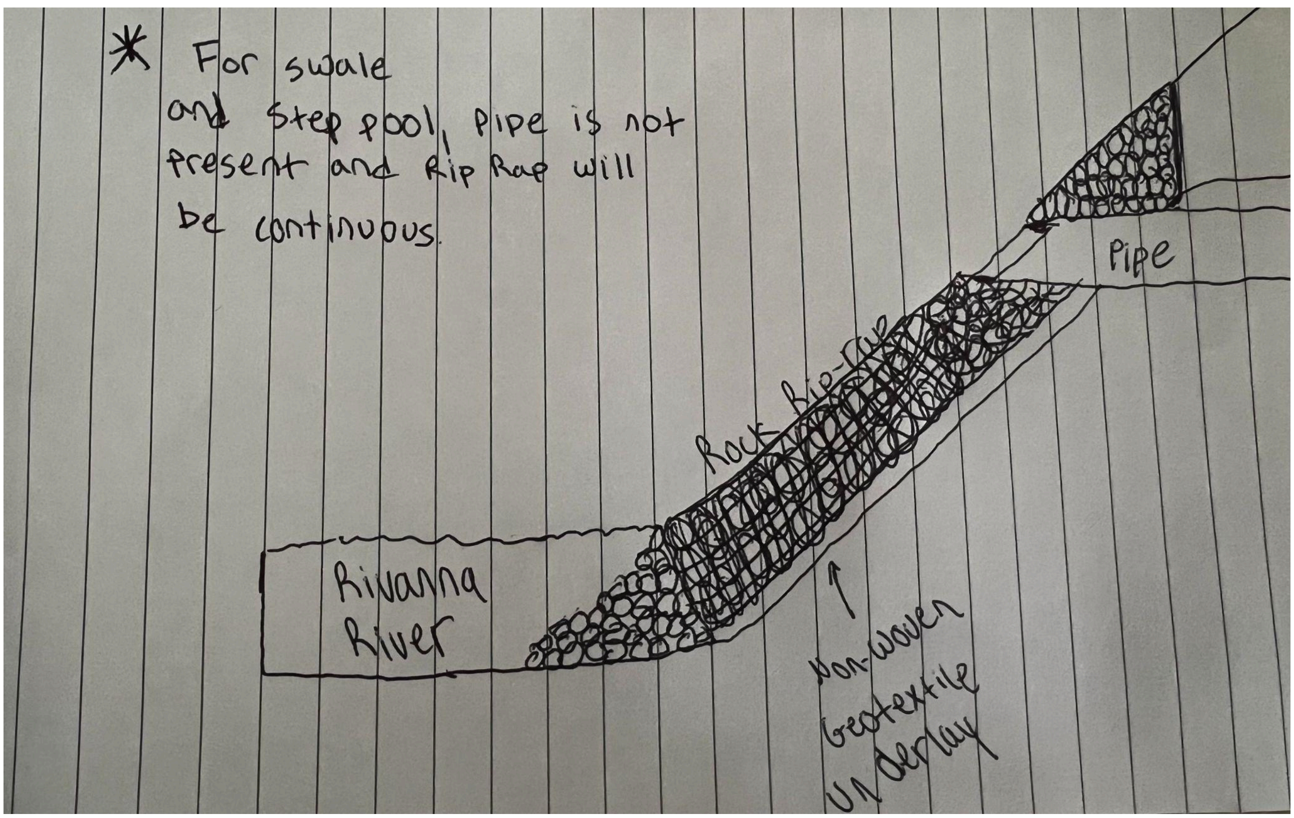


Figure 27: Head cut Repair Design Example

Appendix G: Erosion and Sediment Control Plans

Figure 28: Phase 1 - Demolition Phase of ESCP

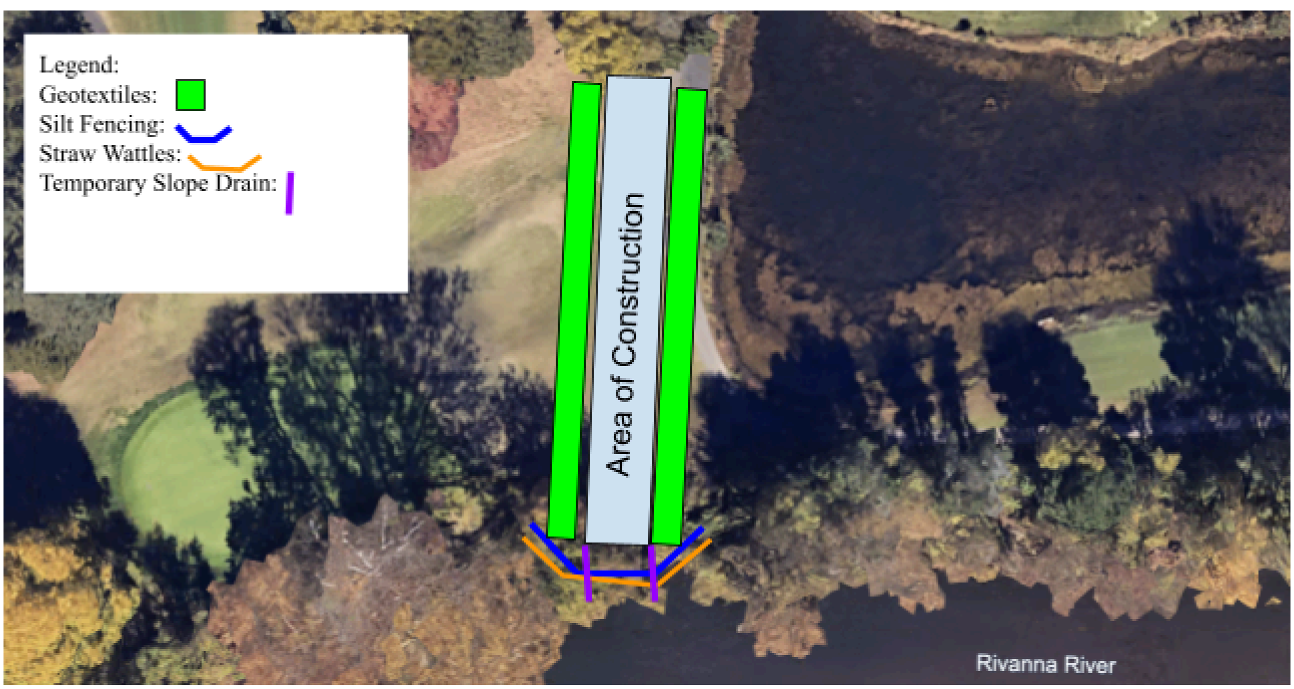


Figure 29: Phase 2 - Construction Phase of ESCP: Design Dependent on Owner Choice

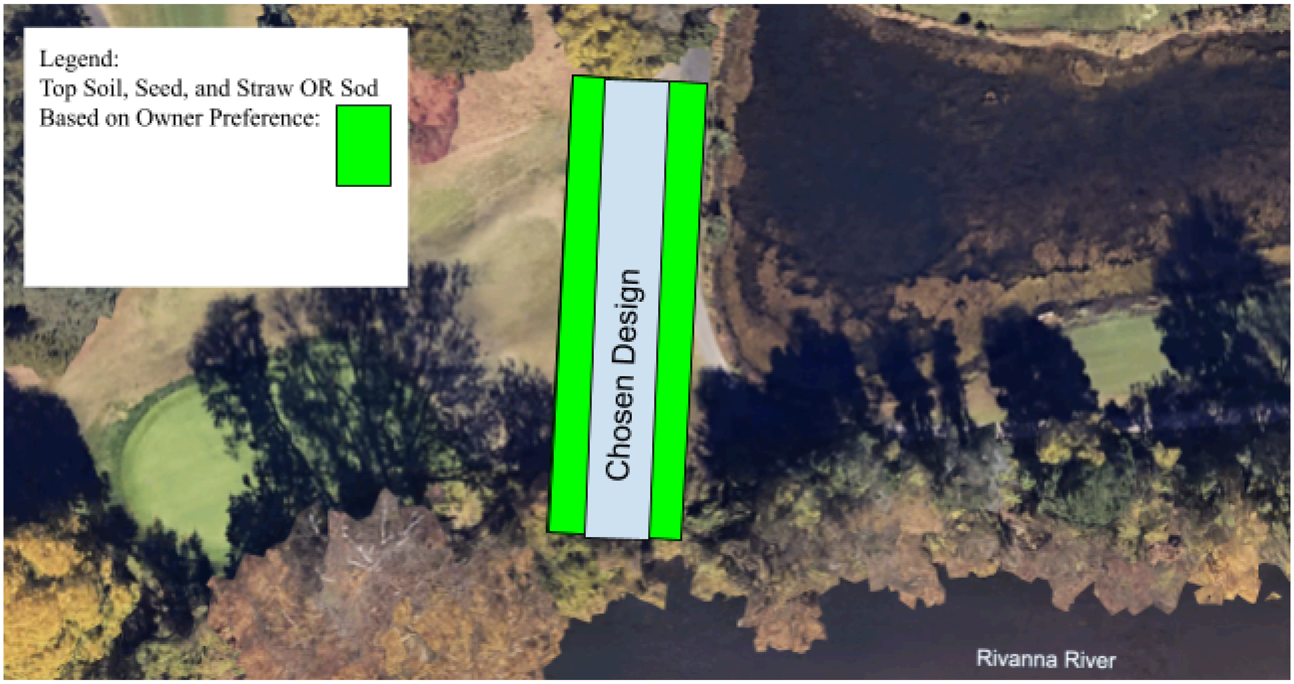


Figure 30: Phase 3 - Post Construction of ESCP

Appendix H: Cost Estimates

Demolition estimate

Component	Cost Estimate	Assumptions	Calculations	Price Source
1. Breaking/Demolition	$10,000 – $20,000	• Removal of a 36″ diameter concrete pipe over 175 ft under a golf course requires careful use of heavy equipment. • Assumes hydraulic hammer/excavator use at 40–60 hours.	• Estimated equipment usage: 40–60 hours at roughly $200–$300/hour yields $8,000–$18,000. • Extra caution and potential manual work (due to proximity to the fairway) rounds the estimate to $10,000–$20,000.	Meadowcreek Estimates (as provided in your file) and typical equipment rental rates (e.g., Wheeler Machinery Rental Rates).
2. Debris Removal	$13,125	• The pipe weighs approximately 1,000 lbs/ft (a common value for reinforced concrete pipe). • For 175 ft, total weight ≈ 175,000 lbs (or 87.5 tons, using 2,000 lbs/ton). • Disposal cost assumed at $150/ton; extra labor/haul fees factored in.	• Weight calculation: 175 ft × 1,000 lbs/ft = 175,000 lbs = 87.5 tons. • Disposal cost: 87.5 tons × $150/ton = $13,125.	Meadowcreek Estimates file (which states disposal costs of $100–$150 per ton) and common industry practice for debris removal.

3. Total Pipe Removal	$23,125-$ 33,125	• Combination of breaking/demolition and debris removal, with the added consideration of working under a golf course where extra care may be needed.	• Sum of above	Derived from the combined figures in the Meadowcreek Estimates file and the Fairfax County Unit Price Schedule guidelines for similar demolition work.

A. Concrete (RCP) Pipe Installation (Excluding Removal/Disposal)

Component	Cost Estimate	Assumptions	Calculations	Price Source
Material (36" RCP)	$286 per LF	Heavy-duty reinforced concrete pipe; cost includes material and handling with heavy equipment.	175 LF × $286 = **$50,050**	From fairfax unit price schedule
Installation Labor	$125 per LF	Average labor rate for a crew of 2–4 workers using heavy machinery on a sensitive site (golf course).	175 LF × $125 = **$21,875**	Based on composite installation rates found in the Fairfax County Unit Price Schedule and corroborated by RSMeans.
Excavation & Backfill	$150 per CY	Trench dimensions of 6 ft deep × 4 ft wide over 175 ft results in approx. 155.6 CY; includes excavation, backfilling, and compaction.	155.6 CY × $150 = **$23,340**	Calculated using standard excavation/backfill rates from the Fairfax County Unit Price Schedule.

Restoration	$10,000	Surface restoration after installation (sodding, grading, reseeding) on the disturbed golf course area.	$50 per square yard, 200 square yards	Based on similar rates on the fairfax county unit price list
Total Installation Cost	**$105,265**	Sum of all components for installing the new pipe (excluding removal/disposal).	$50,050 + $21,875 + $23,340 + $10,000 = **$105,265**	Combined from RSMeans data, Fairfax County Unit Price Schedule, and the Meadowcreek Estimates file.

B. HDPE Pipe Installation (Excluding Removal/Disposal)

Component	Cost Estimate	Assumptions	Calculations	Price Source
Material (36" HDPE)	$275 per LF	Large-diameter HDPE pipe; cost includes fused jointing and anchoring as required; generally lower than concrete but still robust.	175 LF × $275 = **$48,125**	Derived from HDPE cost guidance in the Meadowcreek Estimates file and corroborated by online supplier data and Fairfax County pricing for HDPE.
Installation Labor	$75 per LF	Lower labor rate than for concrete installation, assuming a smaller crew (2–3 workers) with lighter equipment.	175 LF × $75 = **$13,125**	Based on composite HDPE installation costs referenced in the Meadowcreek Estimates and Fairfax County Unit Price Schedule.
Excavation & Backfill	$150 per CY	Same trench dimensions as the concrete installation: 6 ft deep × 4 ft wide over 175 ft (≈155.6 CY).	155.6 CY × $150 = **$23,340**	Calculated using the trench volume and standard excavation/backfill rates

				from the Fairfax County Unit Price Schedule.
Restoration	$10,000	Cost to restore the golf course surface after installation (sodding, grading, reseeding).	Lump sum = **$10,000**	Based on similar restoration projects and cost guidance from the Fairfax County Unit Price Schedule and Meadowcreek Estimates file.
Total Installation Cost	**$94,590**	Sum of all components for installing the new HDPE pipe (excluding removal/disposal).	$48,125 + $13,125 + $23,340 + $10,000 = **$94,590**	Combined from HDPE pricing guidance, Fairfax County Unit Price Schedule, and the Meadowcreek Estimates file.

C. Engineered Dry Swale

Component	Cost Estimate	Assumptions	Calculations	Price Source
Excavation & Grading	$7,500	Swale trench excavation with gentle grading; mid-range value between $5,000 and $10,000.	Selected mid-range value: $7,500	Derived from Meadowcreek Estimates and typical shallow excavation rates from the Fairfax County Unit Price Schedule.
Engineered Soil Mix	$7,500	Placement of a 6-inch engineered soil layer over the swale; based on a mid-range cost between $5,000 and $10,000.	Selected mid-range value: $7,500	Based on cost data from the Meadowcreek Estimates and RSMeans construction cost guides.

Underdrain System	$4,500	Installation of a perforated pipe with gravel; mid-range value between $3,000 and $6,000 for the swale length.	Selected mid-range value: $4,500	Derived from the Meadowcreek Estimates and corroborated by standard underdrain installation rates in public works projects.
Native Plantings	$7,500	Establishment of native plants along the swale; cost includes plants, labor, and soil preparation; mid-range between $5,000 and $10,000.	Selected mid-range value: $7,500	Based on landscaping rates in the Meadowcreek Estimates and Fairfax County Unit Price Schedule, corroborated by RSMeans.
Safety Barriers	$2,000	Installation of low fencing or safety barriers along the swale for erosion control; assumed cost between $1,000 and $3,000.	Selected mid-range value: $2,000	Derived from cost guidance in the Meadowcreek Estimates and similar projects documented in the Fairfax County Unit Price Schedule.

Total Swale Cost	**$29,000**	Sum of all swale components (excavation, engineered soil, underdrain, plantings, and safety barriers).	$7,500 + $7,500 + $4,500 + $7,500 + $2,000 = $29,000	Summed from the above components using data from the Meadowcreek Estimates file, Fairfax County Unit Price Schedule, and RSMeans.

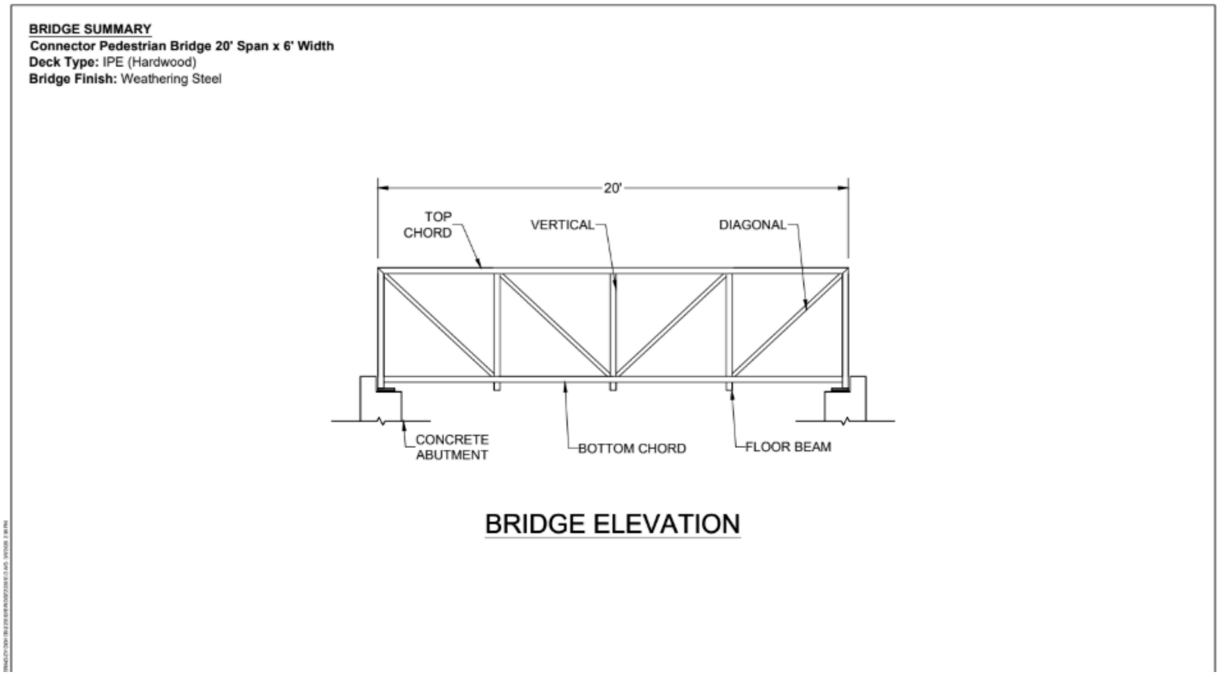
D. Step Pool system

component	Cost Estimate Range	Mid-Range Calculation	Assumptions & Detailed Calculations	Price Source & Reference
1. Earthwork & Grading	$5,775 – $11,550	(5,775 + 11,550) ÷ 2 = $8,662 (≈$8,500 rounded)	• Assume grading costs are $1.50–$3.00 per ft². • For 3,850 ft²: Low = 3,850 × $1.50 = $5,775; High = 3,850 × $3.00 = $11,550.	RSMeans / HomeAdvisor: Typical grading costs range from $1.50–$3.00 per ft². HomeAdvisor Grading Costs
2. Boulders/Rock Armoring	$17,500 – $17,500	(Fixed value based on assumed tonnage) = $17,500	• Assume 50 tons of stone are needed. • Typical cost of rock armoring is about $350 per ton. Calculation: 50 tons × $350/ton = $17,500.	Fairfax County Unit Price Schedule suggests rock fill costs of $200–$500/ton; using a mid-range of $350/ton. Also corroborated by online sources (e.g., RSMeans cost data).

3. Native Plantings	$11,550 – $19,250	(11,550 + 19,250) ÷ 2 = $15,400 (≈$15,000 rounded)	• Assume landscaping cost is $3.00–$5.00 per ft² for native plant installation. • For 3,850 ft²: Low = 3,850 × $3.00 = $11,550; High = 3,850 × $5.00 = $19,250.	Online landscaping cost guides (e.g., HomeAdvisor Landscaping Costs) and typical Fairfax County rates for public landscape projects.
4. Safety Barriers	$2,450 – $4,900	Assume roughly $10 – $14 per linear foot over 350 ft; mid-range ~$3,500	• Assume safety barrier (low fencing/railings) costs $10–$14 per linear foot. • For 350 ft (assuming both sides of the swale): Low = 350 × $10 = $3,500; High = 350 × $14 = $4,900. (We use a mid-range value of about $3,500.)	Fairfax County Unit Price Schedule includes similar items; online fencing cost guides indicate $10–$14/ft for low-cost safety barriers. (HomeAdvisor Fencing Costs)
Total Cost		$44,500		

Pedestrian bridge:
Prefabricated, Steel frame with wood deck (PA-1), 8' wide, $1455 per LF 20 ft x 1455 = $29,100, this is wider than our example so it is conservative estimate. Only applicable to swale and step pool.

Appendix I: Bridge Design



Bridge Type

Pedestrian

Application

Trail Bridge

Bridge Style

Connector

Bridge Width

6 ft.

Bridge Span

20 ft.

Deck Type

IPE (Hardwood)

Life Safety Rail

Horizontal

Rail Height

42" (min) Pedestrian

Bridge Finish

Weathering Steel

Bridge Finish Color

Abutment Type

Cast in Place

Design Code

AASHTO

Abutment Design

By CONTECH

Estimate Requested

No

Appendix J: SPSC Design Calculations

The channel segment requiring restoration extended approximately 180 feet in length, with a total elevation drop of 7 feet at the head cut. This resulted in an average slope of 3.89%. To manage this elevation change effectively, a configuration of two cascade weirs and one riffle weir was selected. Cascade weirs, which typically have a 10% slope, were designed with a height of 3 feet each, resulting in a length of 30 feet per weir (3 ft / 0.10). The riffle weir was designed with a standard drop of 1 foot and a minimum length of 10 feet. After accounting for the total length used by the weirs (2 x 30 ft for cascades and 10 ft for the riffle), 110 feet remained available for the pools. This length was divided among three pools, each approximately 36.67 feet long. A standard width of 10 feet was applied across all pools and weirs for consistency and to meet the minimum width recommendations (8 - 10 ft for cascade weirs and 10 ft for riffle weirs).

Appendix K: Supporting Materials

SharePoint Folder Link

Sources

- Gregg, S., Waickowski, S., & Hunt, W.F. (n.d.). *Regenerative Stormwater Conveyance: Monitoring and Analysis in the Piedmont Region of North Carolina.* Retrieved from https://bae.ncsu.edu/wp-content/uploads/sites/3/2018/08/Gregg-Regenerative-Stormwater-Conveyance.pdf
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- Flores, H., McMonigle, D., Underwood, K., & Pensyl, K. (2022, May). Design Guidelines for Step Pool Stormwater Conveyance (SPSC) Systems . https://www.aacounty.org/sites/default/files/2023-04/aaco-spsc-guidelines.pdf