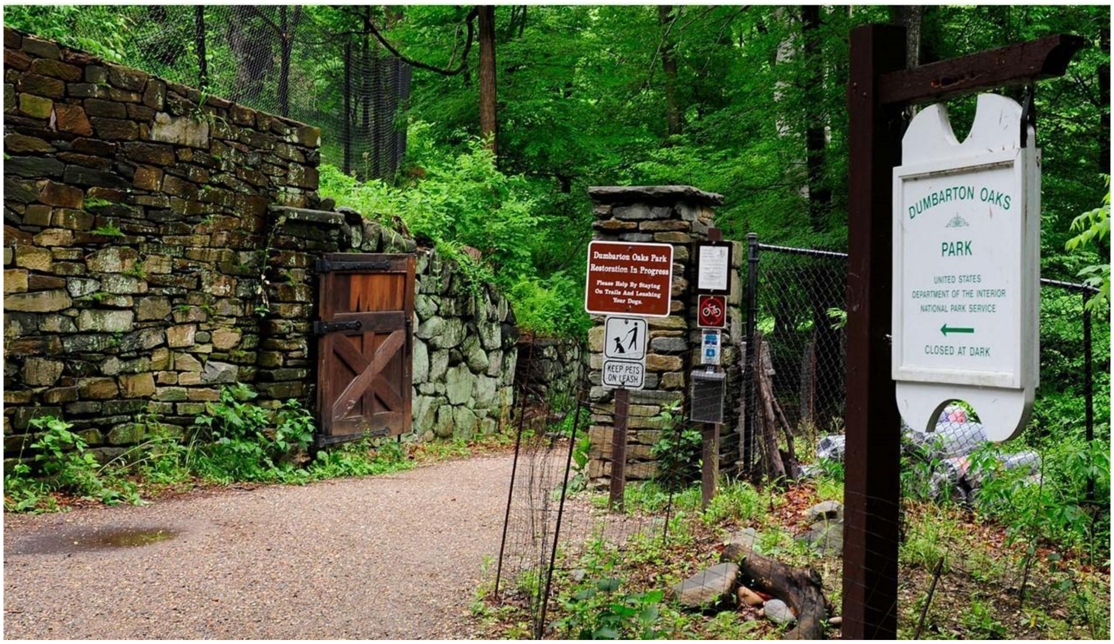
Stormwater Management in Dumbarton Oaks Park



An Interactive Qualifying Project submitted to the faculty of
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Degree of Bachelor of Science.

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Advised by Professor Richard Vaz

Sponsored by Nick Bartolomeo (National Park Service)

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Abstract

Dumbarton Oaks Park in Washington, DC faces excessive stormwater causing erosion and damage to key park features during storm events. Our goal was to propose a low impact solution to the National Park Service that would protect the historic park and manage stormwater. We interviewed park personnel and conducted research to understand the desired traits and feasibility of potential solutions. An ideal solution would blend into the park designer's aesthetic vision and leave the cultural and historical value unchanged. We recommended a constructed wetland to manage the excessive stormwater in Dumbarton Oaks Park and estimated the design parameters for the wetland.

Acknowledgements

Many people provided us with support to achieve the goal of this project. Thank you to Dr. Robert Traver who helped our team develop a proposal to understand the depth of this project. We want to thank our sponsor, Nick Bartolomeo, Chief of Resource Management at Rock Creek Park, for his continued guidance, support, and resources. We would also like to thank Bill Yeaman, Resource Management Specialist, and Dumbarton Oaks Park Conservancy members George Seltzer and Louis Slade for their dedication to this project.

The team members would also like to thank the National Park Service and all personnel who helped us complete our project in some way (listed alphabetically by last name):

- Richard Ayad, National Park Ranger
- Lauren Devore, National Park Ranger
- Jamie Euken, Acting Permits Specialist / National Park Ranger
- Edie Johnston, Chief of Administration
- Bradley Krueger, Cultural Resource Manager
- Lauren Macklin, Centennial Volunteer Ambassador
- Mike McMahon, Landscape Architect
- Matthew Schley, Regional Hydrologist
- Julia Washburn, Superintendent
- Carlton Wourman, Administrative Support Assistant
- Frank Young, Deputy Superintendent

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Executive Summary

Dumbarton Oaks Park is a historical park located in the Georgetown neighborhood of Washington D.C. The park was designed by the famous landscape architect Beatrix Farrand in the 1920s. Farrand designed many features in the park, such as dams and pools, creating a unique and historical landscape. There are 18 dams on the stream to control the water flow, and according to park officials, they were not designed to manage stormwater. An increased number of storm events combined with urban runoff from impervious surfaces neighboring the park has created a heavier water flow, and consequently has damaged many of the historical dams, hindering their ability to control the stream. Many of the dams are not functioning properly, causing the stream to divert around them. The heavy stream flow is also eroding the land surrounding the stream.

The goal of the project was to recommend a low impact stormwater management solution to the National Park Service to control the stream flow and erosion in the park. Our team used the following research objectives to reach the goal of this project.

- **Review park maintenance history:** We interviewed park personnel and consulted records pertaining to projects completed in the park.
- **Assess the damage of the park's features:** We made several visits to the park with park officials and witnessed the damage firsthand.
- **Study the composition of the western watershed and other case studies:** We reviewed cultural landscape and hydrology reports and analyzed soil composition charts and topographic maps of the land. We also reviewed similar case studies in the Washington, DC area.

Findings

We identified information regarding the park damage, factors our project needs to consider, and potential solutions.

- **Damage:** The stormwater problem is not new to Dumbarton Oaks Park. Farrand did not design the dams to function with an increase in stormwater. As urban development around the park and storm events increased, the stormwater runoff increased. The increased water flow has filled the historical dams and pools with sediment and caused them to malfunction.
- **Project Needs:** The recommended solution should not change the historical or cultural identity of the park. The implementation of the solution must follow NPS historical site regulations. The total contributing watershed is about 100 acres (see Figure 1). The proposed project site is between the 31" outfall pipe at the head of the stream and the first of 18 dams in the park (see Figure 2). This area is roughly 5 acres. The solution should also be permanent and capable of supporting a 100 year storm event. Using topographic and soil composition maps, we estimated stormwater values and approximated runoff characteristics of the site. Utilizing Washington DC rain data and the Dumbarton Oaks Park Conservancy geographic information system, our team estimated that 100 acres of the surrounding land drains into the proposed project site.

According to our calculations, the solution must be able to store 30 acre-feet out of 45 acre-feet of runoff produced by a 100 year, 24 hour storm (see Appendix F). As shown in Figure 3, the project site is 20% sand and 75% silt and the remaining 5% is undetermined (WebSoilSurvey, 2019). Different stormwater solutions require different soil composition to support their way of functioning.

Figure 1: The soil types presented at the watershed are hydrologic soil group (HSG). A (pink), B (blue) and C (green), with undetermined urban-complex soil (white) (WebSoilSurvey, 2019).

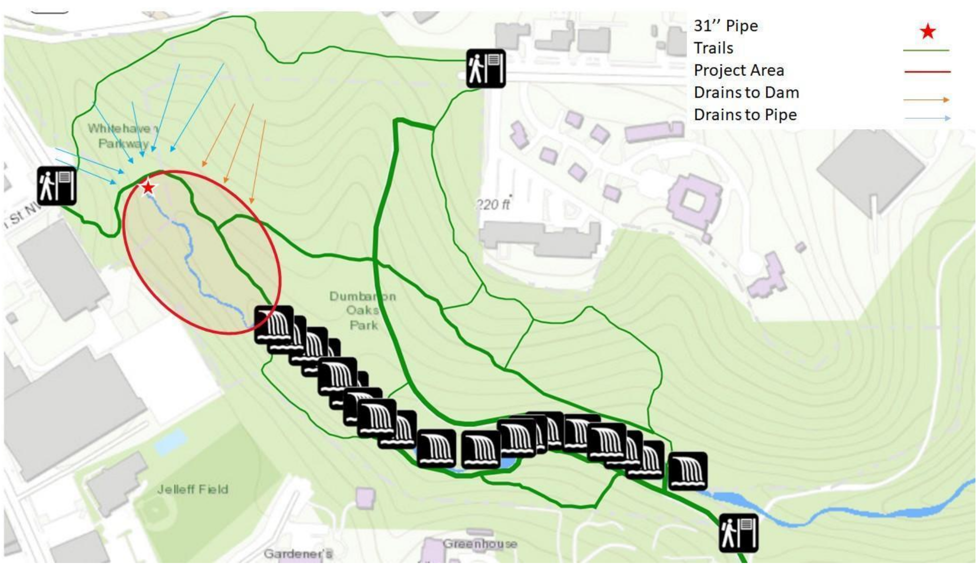

Figure 2: A map of DOP with the proposed project site between the 31’’ pipe and the first dam

Figure 3: A Map that shows the soil types present in the project site (WebSoilSurvey, 2019)

- **Possible Solutions:** After visiting several stormwater management sites in Rock Creek Park, talking with park personnel, and conducting research, we considered piping, regenerative stormwater conveyances, stormwater ponds, and constructed wetlands as options and evaluated them for feasibility. Figure 2 summarizes our evaluation for all the considered solutions.

Solution	Protect park features	Reduce peak discharge	Improve water quality	Disturbance to park environment	Feasibility	Approved by DDOE/DOEE
Piping	Yes	No	No	High	Low	No
Pond	Yes	Yes	No	High	High	No
RSC	Yes	Yes	Yes	Medium to High	Low	In stream: No Upstream: Yes
Constructed Wetland	Yes	Yes	Yes	Low to Medium	High	Permit required

Figure 4: Possible stormwater solutions evaluations

Recommendations

We recommend a constructed wetland as a stormwater solution for Dumbarton Oaks Park. Such wetlands have four major parts as shown in Figure 5. The first is the inflow, which the main source of water in the wetland. The next is the permanent pool, where the wetland habitat resides and serves the outfall with the required flow. The next part is the emergency spillway, which is responsible for discharging the excess water during storm events to maintain the wetland safety. The final part is the outfall, which is responsible for keeping the flow stable to the features after the wetland.

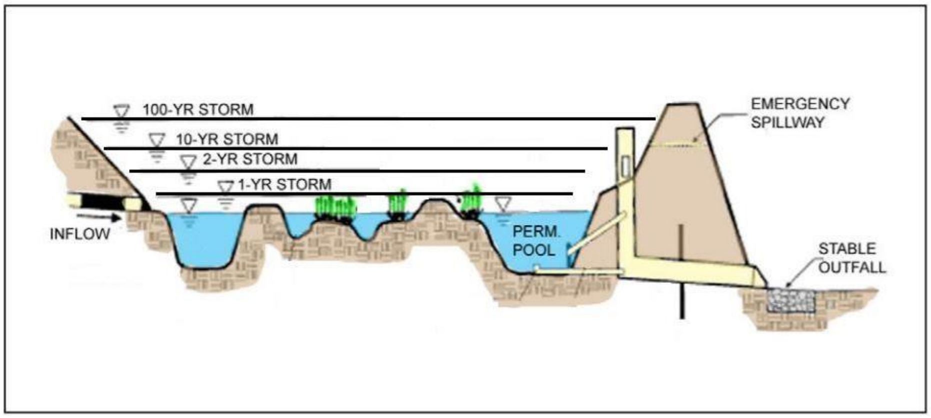

Figure 5: A possible design for the constructed wetland
(Pennsylvania Stormwater Management Manual, 2006)

This solution could control the flow in the stream and help manage erosion in the area surrounding the stream. A constructed wetland could reduce the sediment in the stream. This solution has a low impact and preserves the value of the park while also blending into its aesthetic vision. To protect the downstream features, the constructed wetland needs to have a capacity of 30 acre-feet to control peak downstream discharge from a 100 year storm. Since the area available at the project site is 5 acres, the average depth of the wetland will be 6ft, which is compliant to safety requirements (M. Schley, personal communication, November 22, 2019). Due to the nature of the project site and the water volume, we estimate the cost of implementing this wetland design in the park to be $500,000.

The National Park Service needs to acquire three permits before the beginning of implementation: 1. The US Army Corps of Engineers, permit 404. 2. The District of Columbia Sediment and Erosion control. 3. NPS Special Use Permit (N. Bartolomeo, personal communication, December 5, 2019). Finally, The team recommends that the National Park Service review and edit our calculations and estimations for more accurate data when they move forward with this solution.

Authorship

Each section of the report had a primary author and editor, although we all reviewed and edited the work. Below is a chart identifying the divisions. Abdullah primarily formatted our written documents, and Wail primarily formatted our presentation slides. Interview responsibilities were divided among the group equally.

Section	**Primary Author**	**Primary Editor**
Abstract	Margaret	Abdullah
Acknowledgements	Abdullah	Margaret
Executive Summary	Wail	Margaret
Introduction	Margaret	Abdullah
2.0	Abdullah	Margaret
2.1	Abdullah & Margaret	Wail
2.2	All	Margaret
2.3	Keming	Margaret
3.0	Margaret	Abdullah
3.1	Margaret	Wail
3.2	Margaret	Abdullah
3.3	Margaret	Abdullah
3.4	Margaret	Wail
4.0	Abdullah	Margaret

4.1	Abdullah	Margaret
4.2	Keming	Wail
4.3	Wail	Abdullah
5.0	Wail	Abdullah
5.1	Wail	Abdullah
5.2	Wail	Abdullah
5.3	Wail & Keming	Abdullah
Appendix A	Margaret	All
Appendix B	Margaret	All
Appendix C	Margaret	All
Appendix D	All	All
Appendix E	Abdullah	All
Appendix F	Keming	All
Appendix G	Wail	All
Appendix H	Keming	All

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1.0 Introduction

Excessive stormwater, when unmanaged, causes flooding and erosion. The National Park Service (NPS) is very familiar with this. Headquartered in Washington DC, the NPS maintains many diverse sites across the United States, such as the historical Dumbarton Oaks Park (DOP). Dumbarton Oaks Park, designed by Beatrix Farrand, the pioneer for women in landscape architecture, sits upon 27 acres in the Georgetown neighborhood of DC (Katyv, 2017). The unique area offers visitors an escape from busy city life with trails, meadows, and historical landscape architecture.

DOP currently faces excessive stormwater that is damaging the features Farrand crafted. Impervious surfaces, like roads and parking lots, compromise the infiltration capacity of the land. Increased storm events and the urbanization of land upstream have caused the watershed of the park's stream to flood during heavy storms. Consequently, stormwater runoff has increased and provoked erosion and the destruction of key park features. Dams are leaking and wing walls are collapsing from increased water pressure. Restoration of the park's structures cannot begin until the NPS has a stormwater management solution in place. A proposed solution must consider cultural and historical requirements, feasibility, cost, and aesthetics. Though park officials have considered potential solutions, no one has formally proposed a descriptive, practical, solution encompassing all needs.

The goal of this project was to propose a stormwater management solution for Dumbarton Oaks Park, fit for the geography and effective in preserving the park's cultural history. Along with that solution, we developed a report of the DOP stream's watershed, including existing hydrology and soil data. To achieve these goals, our objectives were:

- Review park maintenance history
- Assess the damage of park features
- Study the composition of the western watershed and case studies
- Recommend a strategy for stormwater management

To meet these objectives, we interviewed park personnel, researched possible stormwater strategies, and made many park visits. We utilized several government databases to determine the topography of the park, the soil composition in the western watershed, and the drainage area of the project site. We made assumptions about stormwater values and runoff characteristics and recommended a constructed wetland as the permanent stormwater solution for Dumbarton Oaks Park. A constructed wetland will control the water flow of the stream and improve water quality. It will also prevent further deterioration of the historical park features while blending into the landscape.

2.0 Background

This chapter of the report will provide a history of the National Park Service, Dumbarton Oaks Park, and the park's designer. It will discuss the current conditions of the park and the issues impacting the site. Finally, we will introduce potential stormwater practices and strategies to manage the park.

2.1 Introduction to Dumbarton Oaks

The federal government placed many different regions of land in the United States under its control in the late nineteenth and early twentieth centuries. They established many memorials, monuments, and parks in the country at this time. Yellowstone and Yosemite National Parks are prime examples. The government conserved these lands so visitors could appreciate their cultural value and natural beauty as well as the history and wildlife (Mission & History, n.d.).

Figure 6: A leaking historical dam in Dumbarton Oaks Park

Each time the government acquired a new area, it was given to a different department (Mission & History, n.d.). To address these multiple management issues, President Woodrow Wilson instituted the National Park Service in 1916 as a federal bureau in the Department of the Interior. Today, the Park Service regulates over 400 areas nationwide (Quick History of the NPS, n.d.). Over 300 million people visit these places each year, making the national parks very popular vacation destinations (Fuller, n.d.). One park that stands out is Dumbarton Oaks, designed by the famous landscape architect Beatrix Farrand.

The National Park Service manages natural, historical, and cultural sites in the United States. Washington DC, the nation's capital, offers a wide variety of historical sites and national parks, including the Washington Monument, Lincoln Memorial, and Dumbarton Oaks Park. Dumbarton Oaks Park is located in the Georgetown neighborhood of Washington DC and is under the management of the Rock Creek Park Office. It covers 27 acres and features landscape architecture like plants, dams, meadows, and streams (Higgins, 2014).

The story of Dumbarton Oaks Park begins in 1920 (Dumbarton Oaks Research Library and Collection, 2017). Robert and Mildred Bliss purchased the land for their dream home. However, the area surrounding the house was unkempt. In 1940, the couple hired Beatrix Farrand, a pioneer for women in landscape architecture, to refurbish the land. Utilizing the land's natural structure and her architecture skills, Farrand designed the historical site of Dumbarton Oaks Park. A few years later, roughly 16 acres of the park and gardens were transferred to Harvard University. The Blisses donated the land to further develop the education of people in the study of humanities. The remaining area was given to the National Park Service and became part of Rock Creek Park.

Beatrix Farrand is known as the first female professional landscape designer in America. Starting from a young age she had a strong passion for plants and gardens. At only five years old, she began to learn about plants while living in Rhode Island. Later, a lucky meeting with John Sargent, an arboretum director, played a huge role in Farrand's career and interests. Sargent noticed Beatrix's passion and guided her toward studying landscape gardening. This guidance changed her career. Sargent suggested that Beatrix travel and learn about landscape architecture. He also offered her the facilities at the Arnold Arboretum to study landscape architecture (The Beatrix Farrand Society, n.d.). The Arnold Arboretum is located in Boston, MA and was designed by Fredrick Olmsted (The Arnold Arboretum of Harvard University, n.d.). Using Sargent's resources, Farrand learned botany, the science of plants. She became proficient in the art of landscape design. This knowledge supported Beatrix as she designed her most famous project, Dumbarton Oaks Park (Beatrix Farrand - "Landscape Gardener", n.d.).


Figure 7: Beatrix Farrand (The Beatrix Farrand Society, n.d.)

Farrand faced multiple problems when designing the Dumbarton Oaks gardens. First, the owners of the land were interested in co-designing the park and had their own style ideas. They wanted the park to highlight certain features in spring and others in autumn. Different structures should have different emphases in each season. Second, the Blisses extended the time for designing the area over many years, and Farrand patiently cooperated with the couple. She only ever proceeded with plans that the Blisses approved and liked, never her own personal ideas. In 1959, Mildred Bliss wrote a remembrance on the occasion of Farrand's death. She spoke of the friendship that formed over several years from the creation of a beautiful garden. Despite the challenges faced while designing Dumbarton Oaks, Farrand left her mark, mixed with the Blisses' taste, in the landscape of the gardens (Bliss, 1959). Figure 8 shows a drawn map of the park today.

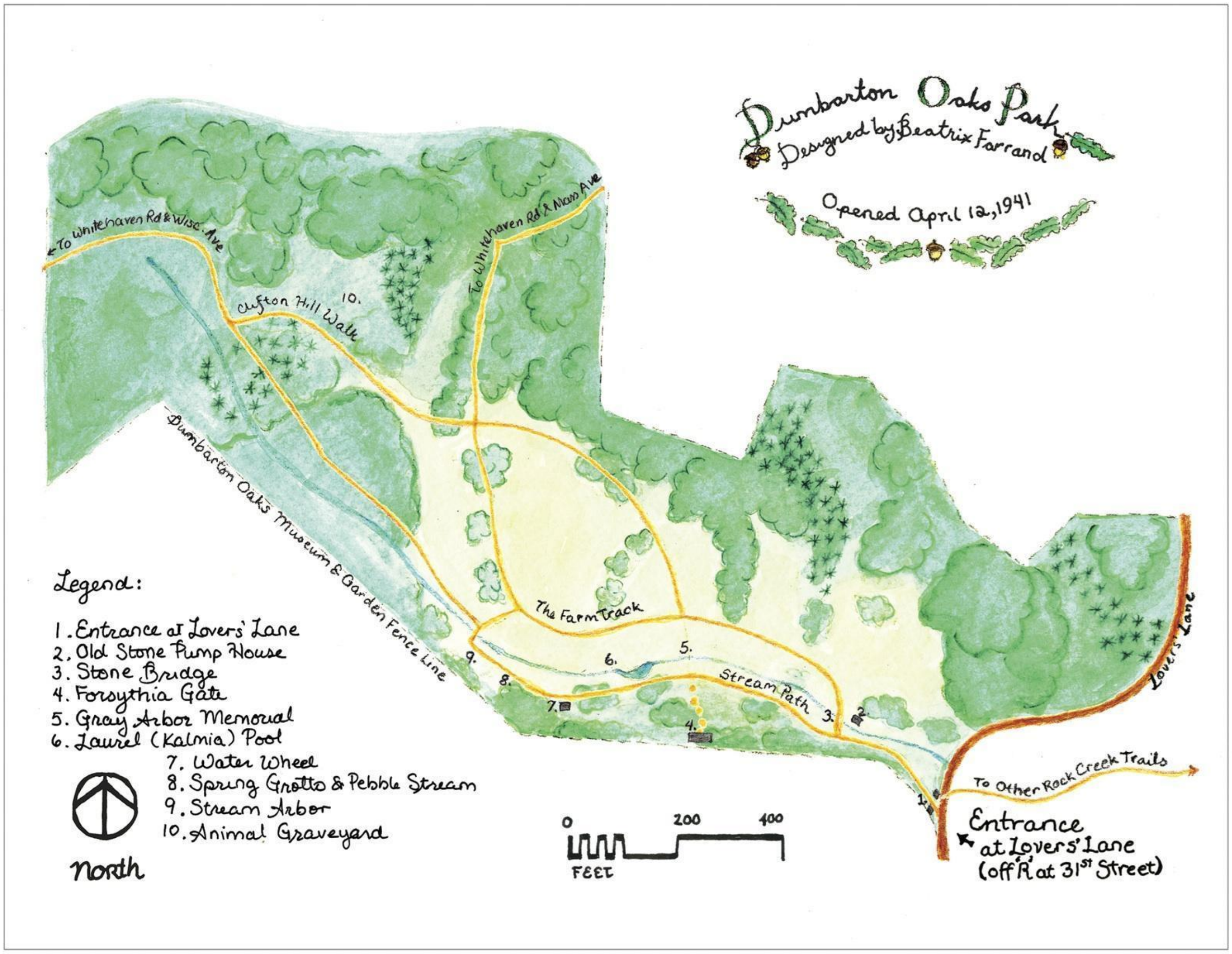

Figure 8: A map of Dumbarton Oaks Park (Dumbarton Oaks Park Conservancy, 2013)

2.2 Current Conditions at Dumbarton Oaks Park

An increase in storms in the area, an increase in impervious lands upstream, and invasive plant species have caused the functionality of park features to deteriorate. These challenges have hindered the ability of the NPS to restore the park. In this section we will discuss the effects of the stormwater problem and the current conditions of the park.

The primary cause of destruction in the park is stormwater. This causes flooding and erosion in the DOP stream (Schlea, 2014). Flooding is when water flow rates exceed the capacity of the channel in a river or a stream. It can also increase the water pressure, causing the features to wear. Flooding in Dumbarton Oaks is causing dams to leak and wing walls to collapse (N.Bartolomeo, personal communication, August 26, 2019). Erosion is the removal of the soil and rock from the stream channel, and it can change the path of the stream (Munoz, 2018). The increasing seasonal precipitation variability due to climate change, accompanied with increase in heavy storms and urban developments upstream, exacerbate the stormwater issue (Kulakowski, 2011).

Urban and suburban developments have caused an increase in stormwater runoff resulting in damage to features. Development and constructions around and within the park valley over the decades have brought about impervious surfaces such as parking lots, roads, buildings, and compacted soil. The natural processes of infiltration, evaporation, and filtering are significantly reduced. As a result, stormwater runoff increases in both volume and speed, contributing to the flooding and erosion to the stream valley and deterioration of features downstream in Dumbarton Run. A hydrologic analysis in 2011 showed that the dam capacity had decreased due to stormwater damage to structures throughout the years (Anderson, 2014). The issue was exacerbated after a drain was installed to channel runoff from the parking lot down to the Dumbarton Run through the main storm sewer pipe (N.Bartolomeo, personal communication, August 26, 2019). Thus, the demand for effective stormwater management practices to mitigate the runoff and prevent further degradation to features becomes increasingly urgent.

Dumbarton Oaks Park contains many structures; some are manmade while some are natural. Examples of man-made structures include dams, wing walls, and stone bridges. Examples of natural structures include streams and waterfalls. Many of these features are subject to flooding and erosion. In Dumbarton Oaks Park, there are eighteen dams, one pool, and three bridges shown in Figure 9. Beatrix Farrand crafted all these features, and they are historically significant.

Figure 9: A map of the historical dams, pool, and bridges in Dumbarton Oaks Park

The unique landscape and soil composition of the valley also pose challenges for managing the park. According to landscape architecture research on Dumbarton Oaks Park conducted by the University of Washington in 2014, historic topographic maps of DC show that the region's position lies on the fall line, or the boundary between the Rocky Piedmont and the unconsolidated sediments of the Atlantic Coastal Plain (Anderson, 2014). The Rock Creek defines the border between the Piedmont to the west, and the Coastal Plain to the east. Therefore, Dumbarton Oaks Park is located along a zone characterized by transition and instability. Although the fall line landscape is suitable for industry because energy of falling water is easy to harness, it is also known for being notoriously erosive. While the gravel and sand on ridges and steep slopes of Dumbarton Oaks Park are very easily eroded, the valley floor is covered by relatively impermeable saprolite that encourages rapid runoff during storm events and increases the risk of erosion, as well as sedimentation in the stream responsible for the deterioration to the features (Anderson, 2014).

Plant management is another challenge for Dumbarton Oaks. There are many kinds of plants in the park, including native and exotic. Beatrix Farrand specifically chose native plants for the park, while the exotic plants have invaded the area (Higgins, 2014). The Dumbarton Oaks Park Conservancy is managing the exotic plants.

The shifting hydrology of the valley is also a challenge to the park management. Eighteenth century maps trace multiple tributaries feeding into the Dumbarton Run, whose headwaters once began on the grounds of the present-day Naval Observatory. As a tributary of Rock Creek, which drains into the Potomac River, the water stream in Dumbarton Oaks Park is part of the Chesapeake Bay watershed. The valley drops 200 feet in elevation from the headwaters to the stream's confluence with Rock Creek. Ancient water patterns are inscribed in the topography. The fluvial terraces and floodplains formed by the movement of the creek over time are still convergence points for overland flows, as shown in Figure 10. This corresponds to the location of Farrand's pools and increased zones of erosion and sedimentation today (Anderson, 2014).

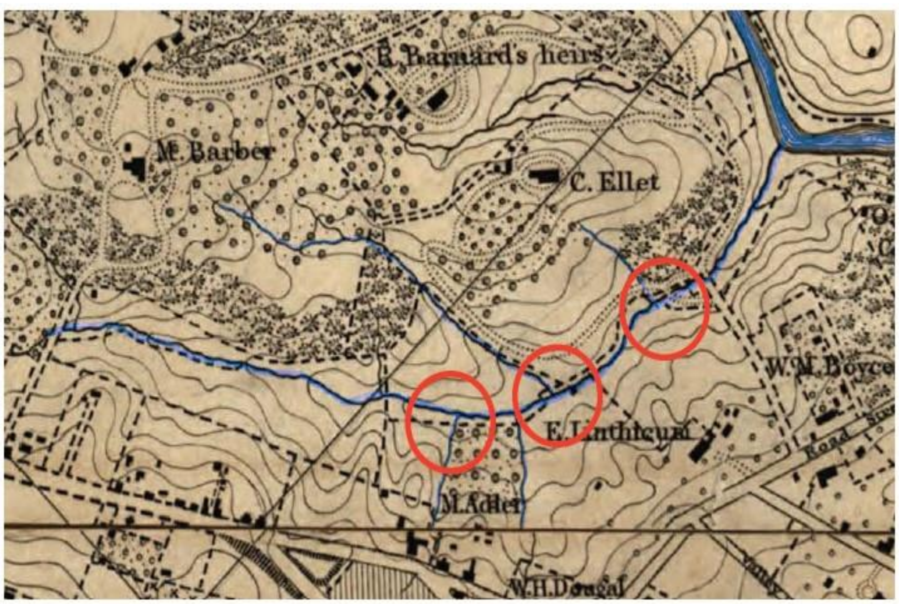

Figure 10: Map of the capital showing Dumbarton Run and its confluvial points (circled in red) with historical sub-tributaries (Boschke, 1861)

Today, several organizations are committed to conserving the park. A non-profit organization called The Dumbarton Oaks Park Conservancy (DOPC) has played a large role in supporting the rehabilitation of Dumbarton Oaks Park. Founded in 2010, this organization helps restore the landscape garden design that has been destroyed by natural causes (Dumbarton Oaks Park Conservancy, 2019).

The conservancy has initiated three major projects to restore Dumbarton Oaks Park so far. Figure 11 depicts one of the volunteering opportunities managed by the DOPC that helps restore Dumbarton Oaks Park. First, the Stormwater Mitigation Plan identifies several areas in the park that need to be controlled. Controlling an area means reducing flooding. The second project is the Signature Project. Several organizations, such as the National Park Foundation and Rock Creek Park, cooperated to assist the project. This project works on finding natural low-cost solutions to the damaged park features. Lastly, the Dumbarton Oaks Park Conservancy sponsored the Meadows Pilot Project. It focuses on clearing the meadows in the park from harmful plants, such as invasive species. To rehabilitate those meadows, several stages of work were planned, since 2014, to cover a larger portion of the park.

Volunteers with Casey Trees installing new trees and shrubs around the biodegradable coir logs installed earlier to decrease erosion and increase groundwater supply. Spring 2014.

Figure 11: Volunteers helping with one of the projects (The Dumbarton Oaks Conservancy, n.d.)

All three projects were done by volunteers, as shown in Figure 11. The Dumbarton Oaks Park Conservancy also holds many volunteering events during the year. The organization also celebrates events related to Dumbarton Oaks Park to enjoy and appreciate its culture.

2.3 Stormwater Management Practices and Solutions

Stormwater management is the control of stormwater runoff. It encompasses planning for runoff, maintaining stormwater systems, and regulating the collection, storage, and movement of stormwater. Many solutions are available to reduce peak stormwater flow, improve water quality and prevent pollution and erosion to watersheds. These solutions include stormwater control measures (SCM) or best management practices (BMPs). A hydrologic study conducted in 2010 assessed the performance and limitations of current stormwater management solutions (Lawrence, 2010). Such practices include:

1. Structured BMPs like Extended Detention Ponds that hold the runoff until the sediment settles down in the bottom and then slowly release it into the nearby waterbody

2. Wet Ponds that allow incoming runoff to replace the pond water and store it until the next storm event

3. Infiltration Basins that store stormwater until some or all of it infiltrates into the surrounding soil

4. Porous Pavement constructed of interlocking tiles and bricks that enhances stormwater infiltration and provides erosion control

5. Water Quality inlets that capture sediment, oil and grease before runoff is discharged. Others include vegetative BMPs that utilize vegetation to enhance stormwater infiltration and storage, as well as Managerial BMPs that regulate the discharge of pollutants and prevent damage to hydrologic features by zoning and setting construction restrictions.

Each solution has its own strengths and limitations on pollutant removal and energy dissipation for runoffs. The determination of a management practice should take the site's physical constraints, the management goal, and the cost into account (Lawrence, 2010). For Dumbarton Oaks Park, the objective of stormwater management is to mitigate runoff while protecting the features and landscape from further erosion. The purpose is also to prepare the park for future restoration (N.Bartolomeo, personal communication, August 26, 2019). The requirement for maximum compliance with Farrand's original landscape vision shines light onto more advanced, visually pleasurable and cost-effective stormwater management systems known as Low Impact Development (LID) or Green Infrastructure (GI). Such practices include:

1. Conserving green gardens that preserve natural area during development

2. Rain gardens in which decorative plants and soil filter runoff and enhance infiltration

3. Bioretention gardens with underdrain systems managing water level and plant growing conditions while improving infiltration

4. Stream restoration that returns damaged streams to natural, open channels (Holm, 2014)

5. Regenerative Stormwater Conveyances (RSC) consisting of cascading aquatic beds and overflowing pools that encourages infiltration reduces runoff pollutants through various physical, chemical and biological mechanisms (N.Bartolomeo, personal communication, August 26, 2019). See Figure 12 for example.

6. Constructed wetlands that create shallow wetland areas to treat urban stormwater and often incorporate small permanent pools and/or extended detention storage to achieve water quality improvement, erosion and flooding prevention, and downstream channel protection (Maryland Stormwater Design Manual, 2000).

Although plenty of measures are available, information specific to the particular problems that Dumbarton Oaks Park faces will help in selecting suitable practices. In 2015, the National Park Service initiated the Environmental Assessment process for establishing a Low Impact Development stormwater management facility in the area known as Reservation 357 (see Figure 13) located beside Whitehaven Parkway, upstream of

Dumbarton Run. The proposed site resembles a detention basin with sediment trap and vegetation around. The goal of the facility was to capture, slow down and filter overland runoff from nearby major sources including the Naval Observatory, Whitehaven Street, Wisconsin Avenue and other private properties before flowing through the main pipe into Dumbarton Run. However, in 2017, the Navy installed a stormwater drain at the Naval Observatory parking lot. Instead of flowing overland and infiltrating into the basin as before, the runoff now enters the main storm-sewer pipe directly with a much greater rate and velocity of flow. As a result, the stormwater capacity of the reservation becomes insufficient and the demand for new stormwater management facilities arises (N. Bartolomeo, personal communication, August 26, 2019).

Figure 12: A Regenerative Stormwater Conveyance (RSC) under construction (Carriage Hills, 2009)

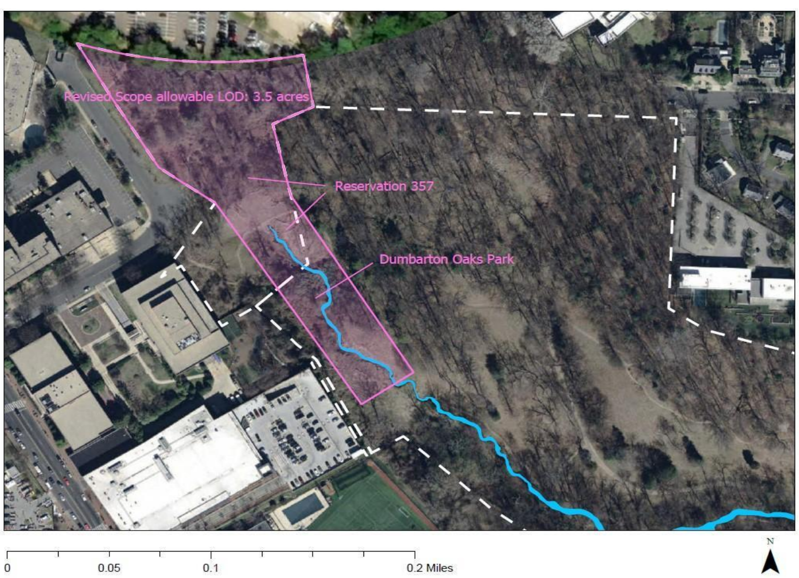

Figure 13: Reservation 357 upstream of Dumbarton Oaks Park (N. Bartolomeo, personal correspondence, August 21, 2019)

Based on the situation, three alternative constructions were proposed for the facility. The first is building a LID structure to capture all main pipe runoff. While the outfall occurs at Reservation 357 outside of Dumbarton Oaks Park, it requires part of the structure to be built within the park (see Figure 14). The second alternative will decouple pipes feeding the main pipe from Whitehaven Street, Wisconsin Avenue, and the Naval Observatory Parking lot. Then, it will direct the flows to a LID structure to be constructed at the upper elevation of Reservation 357 above the outfall. Although runoffs from these three sources would

Figure 14: The LID (green outline) capturing all runoff from the 31’’ pipe as described in the first option

infiltrate into land before the outfall, an additional LID structure is still required likely within the park for remaining flow in the main pipe. However, the required capacity for the in park structure would be much less than the one mentioned in the first alternative (see Figure 15). The third alternative is to reconstruct pipes at the three sources together with the main pipe and redirect all runoffs to one single LID structure to be constructed at the upper elevation of Reservation 357. Due to the large capacity requirement, the structure will likely extend into the park. But the in-park portion of the structure would be the smallest among all three alternatives. However, a diverter is required to maintain a base flow through the main pipe into the Dumbarton Run while directing exceeding flow into the structure (see Figure 16).

Besides the LID structure, an overflow structure is also required to deliver overflow to a separate stormwater drain system or nearby landscape so the overflow will eventually permeate into the ground instead of entering Dumbarton Run and cause further erosion. Also, the facility would serve as an engaging entrance to the park, a learning lab for urban stormwater management and wildlife habitat development, and a demonstration for community partnership in environmental improvements (N.Bartolomeo, personal communication, August 26, 2019).

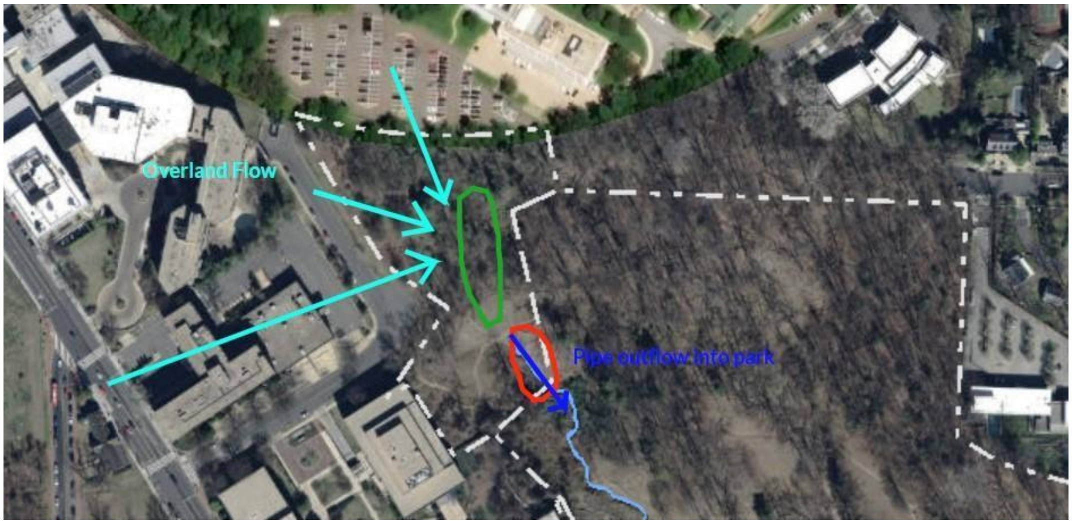

Figure 15: The LID (green outline) capturing runoff from Whitehaven Street and Wisconsin Avenue, and another LID capturing remaining runoff from the 31” pipe

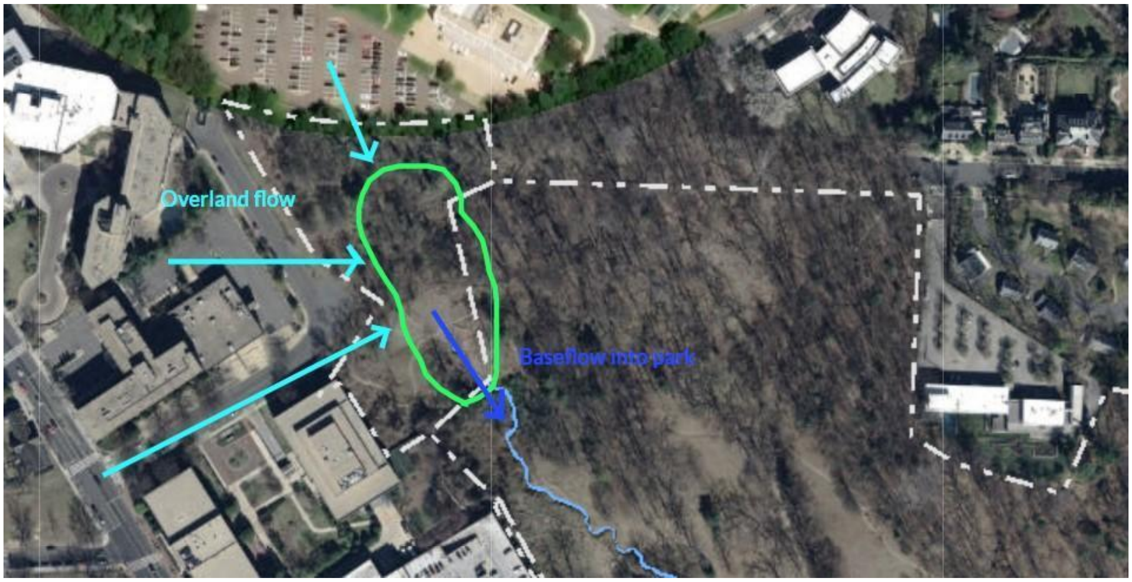

Figure 16: The LID (green outline) capturing all overland runoff and supplying base flow into the stream

3.0 Methodology

The project objective was to recommend to the National Park Service (NPS) a potential stormwater management solution for the western watershed of Dumbarton Oaks Park (DOP). In this chapter, we describe the following research objectives: 1. Reviewing the maintenance history of the park; 2. Assessing the damage of the park's features; 3. Studying the composition of the western watershed; and 4. Recommending strategies for stormwater management. Our objective was to identify a solution most suitable for the park's history and needs. We reported our findings to the NPS for them to decide the next step of action.

3.1 Review Park Maintenance History

To understand aspects of the park's history relevant to our goal, we wanted to answer the following research questions: 1. How has the park been managed and maintained? 2. How long has stormwater been causing damage? and 3. What initiatives has the Dumbarton Oaks Park Conservancy undertaken? To answer these questions, we conducted interviews with park personnel and consulted park records. We interviewed conservancy members to learn about the removal of invasive plants, the dredging of sediment, and the addition of sandbags to dams in the park. We reviewed cultural landscape reports to gain an understanding of the conditions in the park over the past few decades and what actions the NPS has taken to care for the land.

3.2 Assessing the Damage of the Park's Features

To understand the cultural significance of the park and the degree of damage, we studied Beatrix Farrand's original plans for the park. Research questions included: 1. What are the key features of the park and their functionality according to Beatrix Farrand? 2. How has the functionality of each changed? and 3. What plants and features did Farrand specifically choose and why? We wanted to learn if the park functions differently than it once did. The answers to these questions assisted us in assessing the degree of severity.

NPS resources and an interview with the Chief of Resource Management for Rock Creek Park provided some answers to our research questions. Trips to the park with park personnel in clement and stormy weather gave us helpful information as well. This insight into Farrand's aesthetic vision helped us as we proposed a stormwater solution cohesive with the park's design. We compared and contrasted the current state of the features to records of Dumbarton Oaks Park throughout the years. Then, we posed a feasible, low-impact stormwater management solution considerate of the landscape.

3.3 Studying the Composition of the Western Watershed and Other Case Studies

To provide guidelines and suggestions for stormwater management solutions, we evaluated previous case studies and studied the watershed of the stream. We sought to learn: 1. What are some stormwater management methods the NPS has implemented in other places? 2. On what basis were they were chosen? 3. Would they work for DOP's watershed? and 4. What is the nature of the water flow in the park?

Some landscapes work better for rain gardens, some for stream daylighting, wetlands, detention ponds, etc. Each option's feasibility is contingent upon many factors, like the proposed location's geography and topography, the cost, and how it blends into the park's landscape. We used these evaluation techniques as we proposed a solution to the NPS. In particular, we categorized the soil by storage capacity and defined our proposed solution area using topographic maps. The maps helped us model the water flow and assume drainage areas. We defined our solution area to be upstream from the first dam and downstream of a pipe in the park.

Hydrology reports of Rock Creek Park educated us about several potential stormwater management methods and their effectiveness. Online government interactive maps helped us classify soil types. The varying stream conditions and soil types impact the choices of possible stormwater management systems. Knowledge of the soil composition gave us insight into the physical foundation of the park and the feasibility of certain solutions. We also spoke with NPS Regional Hydrologist Matthew Schley to learn about the hydrology of the park, like the stream's water capacity and flow rate. To supplement this information, we researched the details and requirements of specific stormwater management structures.

3.4 Recommending Strategies for Stormwater Management

We wanted a solution that is feasible for Dumbarton Oaks to implement. Questions we considered as we progressed were:

1. Is this solution compatible with the park's geography and topography?
2. Will this solution effectively mitigate the water flow damaging park features?
3. Does this design blend into the landscape, and is it aesthetically pleasing?
4. Is this solution cost efficient?

We went through several rounds of developing and evaluating solutions based on feedback from park experts until they identified a constructed wetland as most promising. After conducting all our research and analyzing data, we developed a potential solution for Dumbarton Oaks Park. The final report has all the water and soil data for DOP that our team used so that the National Park Service has it all in one place and the evaluated solution we see best fit for the park.

4.0 Findings

In this chapter, we present information about the western watershed of Dumbarton Oaks Park, otherwise known as the area surrounding the stream. Soil, hydrology, and the park's historical features are all areas to focus on. We then describe a stormwater solution's requirements. Finally, we will present several possible stormwater management solutions in detail.

4.1 Conditions in the Western Watershed of Dumbarton Oaks Park

In this section, we will discuss the conditions of the area affected by heavy water flow. From park visits we learned that the NPS has not undertaken any major projects to protect DOP due to lack of resources and experience. The park's features are not functioning well, especially dams. The heavy water flow has changed the stream's path designed by Beatrix Farrand by eroding the land. Shown in Figure 17 is a new route for the water flow that was made by excessive stormwater. Figure 19 shows the increased sedimentation in the pool, which is labeled in the map in Figure 18. This pool was installed at almost the middle of the stream to control flow velocity, but it does not function well due to increased sedimentation.

Figure 17: New stream line made by erosion

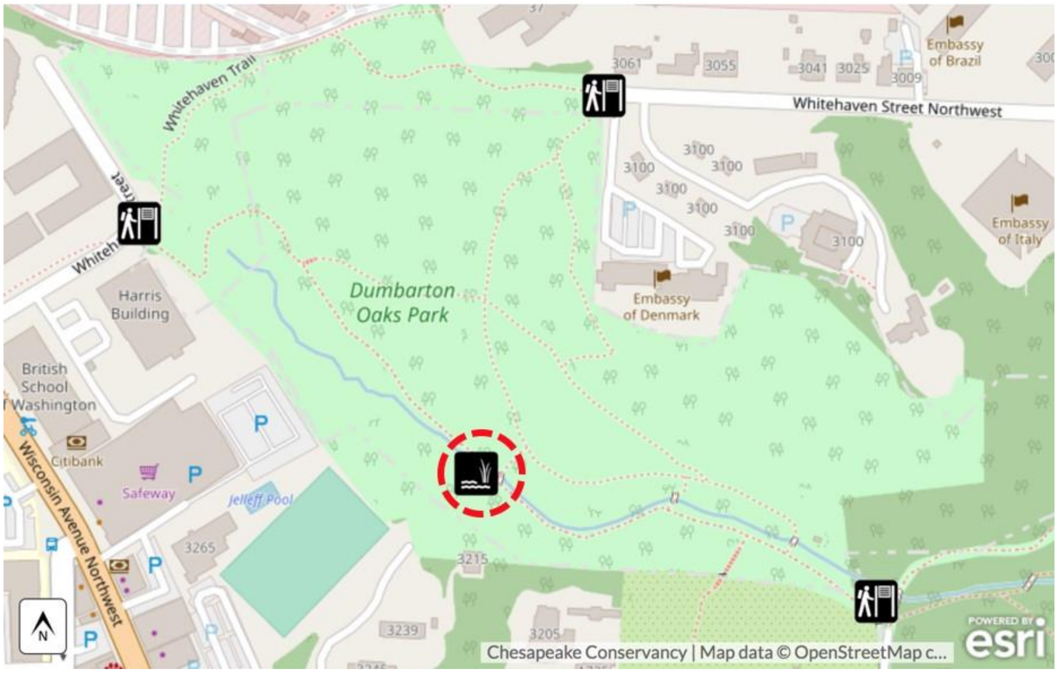

Figure 18: The pool designed by Beatrix Farrandlabeled in a map of DOP

Figure 19: The Clapper Bridge Pool designed by Beatrix Farrand

Figure 21 shows one of the flooded historical dams, which are labeled in Figure 20. The problem of flooding is affecting all the eighteen historical dams labeled in Figure 20.

Figure 20: Eighteen historical dams labeled in a map of DOP

Figure 21: One of the historical dams in DOP

As labeled as a star in Figure 23, a main pipe that is 31” in diameter, at the beginning of the stream, discharges water that flows in the stream, shown in Figure 22. Stormwater is the main water source that goes through this pipe in DOP.

Figure 22: The main 31” pipe in DOP

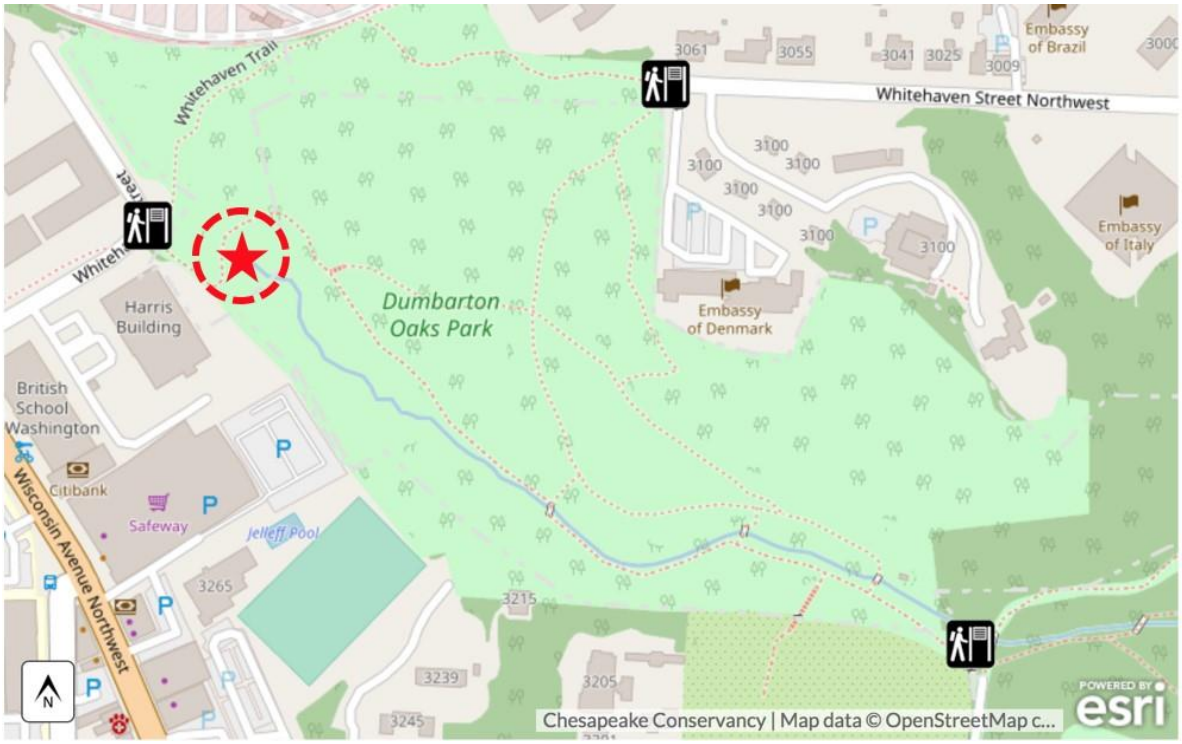

Figure 23: A map showing the location of the main 31” pipe (labeled as a red star)

From several meetings and tours around the park with Louis Slade and George Seltzer, members of the DOP Conservancy, we learned that this pipe runs continuously during the year. In addition to stormwater, the pipe discharges water from several unknown sources. The water drainage area must consider all possible water sources, as shown in Figure 24. Therefore, as mentioned in Appendix D, we came up with a list of assumptions. We presumed the drainage area, the water flow rates, soil types in DOP, and other minor assumptions.

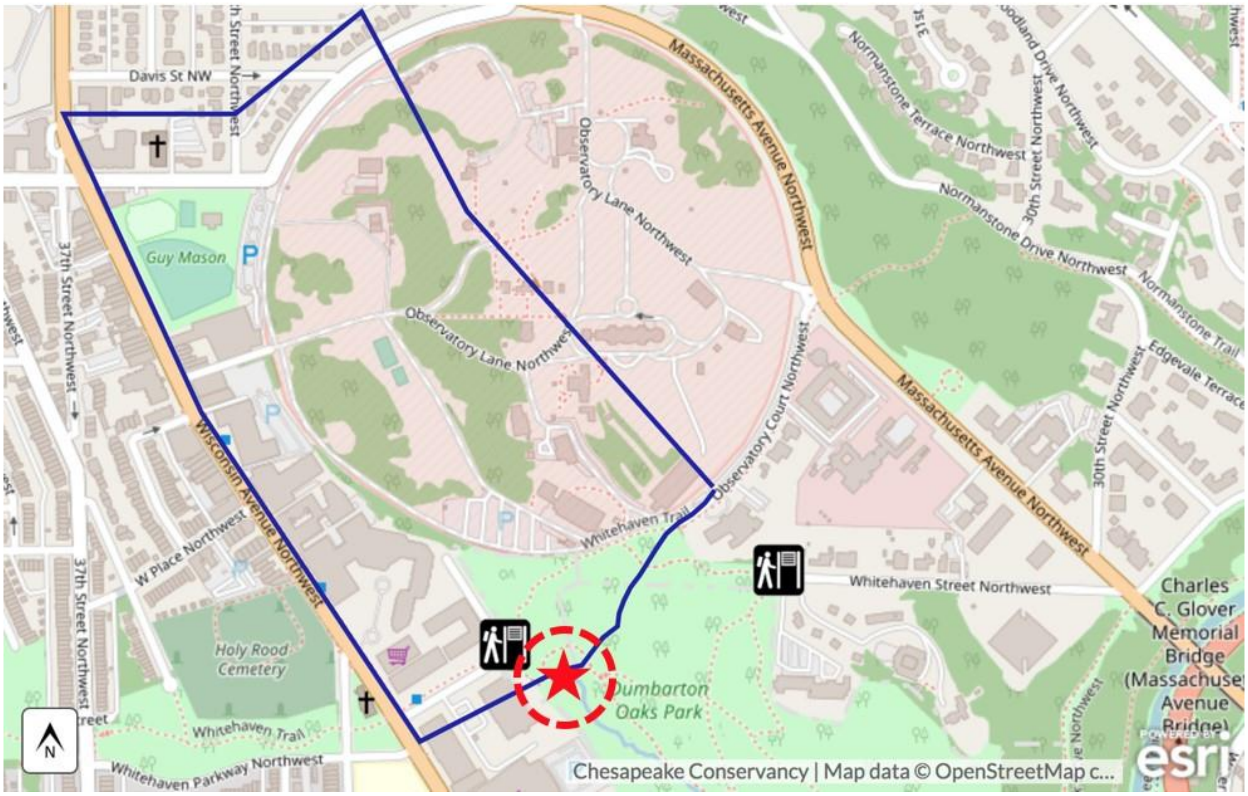

Figure 24: The drainage area of the water runoff that goes to the main 31” pipe

As shown in Figure 24, the pipe delivers stormwater runoff from a large urban area of about 100 acres (see Appendix F). This area includes almost half of the Naval Observatory and other impervious surfaces north west of DOP. As mentioned in Appendix D, we made assumptions about the amounts of water coming from all the different sources, shown in Figure 24, into the main pipe in order to be able to recommend a solution.

Soil composition is an important factor to be considered when determining a stormwater solution. We relied on an online tool (WebSoilSurvey, 2019) to study the soil in the project area. As a result, as shown in Appendix E, we approximated that the soil in the area of interest presents a mixture of sand and silt. Sand drains water quickly, while silt slows drainage and holds water. The project area might need clay to give more options to the NPS regarding stormwater solutions, such as wetlands.

4.2 Requirements of a Stormwater Solution

According to our observations in the park, research from available literature, and results obtained from interviews with NPS personnel, a solution that slows down runoff and improves water quality is favorable. In this section, we summarize some general requirements that a DOP solution must meet.

As previously mentioned, the goal of our project was to recommend a low impact stormwater management solution. To achieve this goal, the solution should have a low impact on both the historical features and the nature of the park. According to the literature and park personnel, the region upstream of the first dam where no historical features are present is the best place to implement the stormwater solution. Because of that, our team proposes the area between the outflow of the 31'' pipe and the uppermost dam to be the project site (see Figure 25 This region of the stream is the easiest place to control the water flow because the stream is uninterrupted and closest to the outflow pipe. The proposed project site is approximately 5 acres. The distance between the 31'' pipe and the first dam is around 600 feet and the width of the project site is around 400 feet.

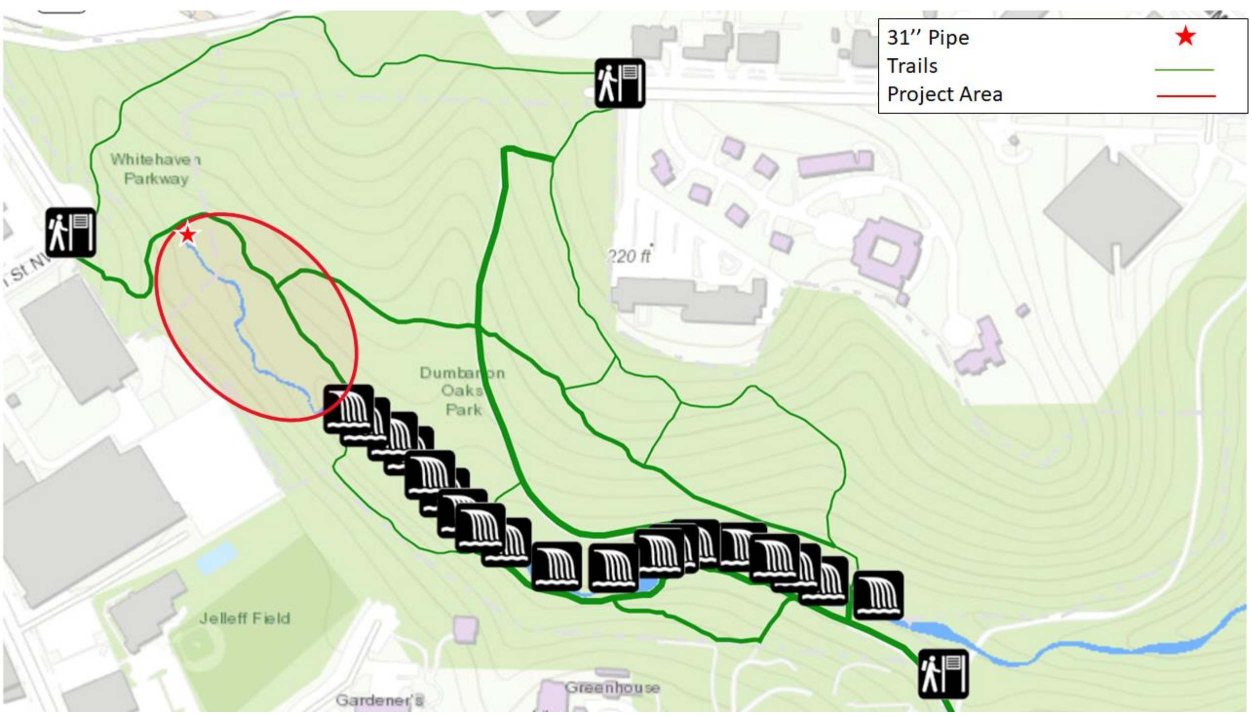

Figure 25: The proposed project site topographical map with respect to the outflow pipe and the historical dams

The solution should also conform to the topography of the project site to facilitate capture and treatment of stormwater runoff to preserve park features. The solution needs adequate storage volume for runoff treatment and reduction downstream for peak discharge during heavy storm events. The water quality treatment volume is maximally 95% of the total runoff volume resulted from a designated storm that has greater precipitation than 90% of the storms in the region (Schueler, 1992). However, the safety maximum storage volume should be able to handle a 100 year storm (Urban Drainage and Flood Control District, 2016) which is 8.37 inches for the region (NOAA Atlas 14). The required storage volume of the solution is determined by the type of rainfall, total runoff volume, and the ratio between the peak inflow and outflow rates (USDA, 1986). The total runoff volumes and peak inflow rates resulted from different storms can be determined by characterizing land cover and soil type of the contributing watershed, consulting NOAA precipitation frequency estimates for storms of different frequency, and input watershed and flow path data into the Win TR-55 computer program (see Appendix F). An outlet facility is required to limit the discharge under the capacity of the West Laurel Fall dam (see Figure 26), which is 4.3 cubic feet per second during heavy storms (Greenhorne and O'Mara, 1999).

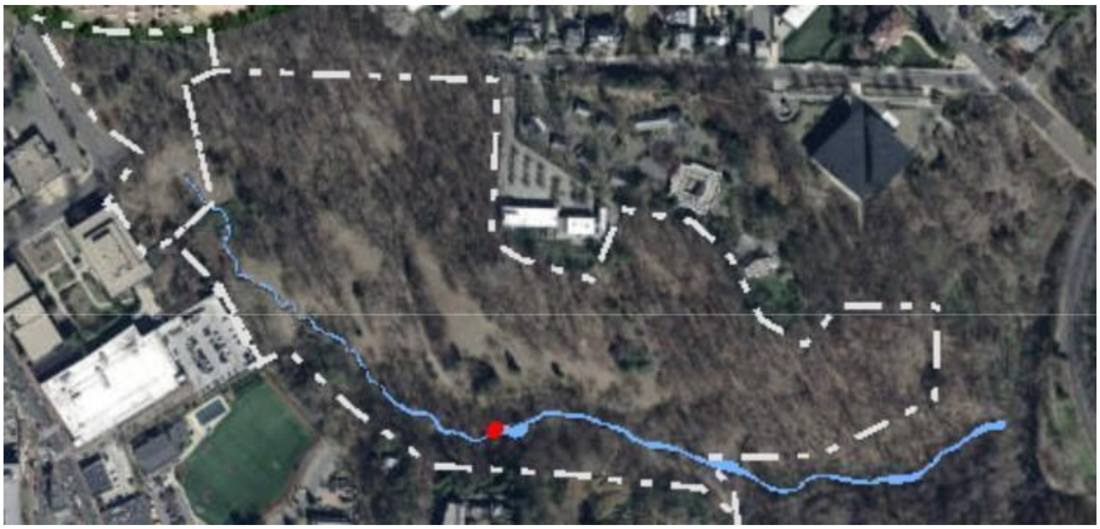

Figure 26: The location of the West Laurel Fall as indicated by the red dot

In order to effectively facilitate runoff treatment, an inground solution needs the soil to be somewhat impermeable to minimize infiltration with permeability less than 10^{-6}cm/sec and clay greater than 15%, which corresponds to Hydrologic Soil Group (HSG) B, C and D (Environmental Protection Agency, n.d.). While most of the soil at the proposed site is in HSG C, minor soil engineering will be required to account for the presence of some excessively well to well drained HSG A soil.

The solution should also employ native plants and appear aesthetically compatible to the surroundings and the features in the park. The construction and the maintenance of the solution should also cause minimal disturbance to the environment and historical features of the park.

4.3 Stormwater Management Options

This section focuses on solutions we considered based upon research and discussion with NPS officials and members from Dumbarton Oaks Park Conservancy (DOPC). Figure 40 at the end of the section summarizes each option with respect to the criteria discussed.

Piping: The first stormwater solution was piping. The idea of piping is to use an underground pipe to divert the outflow of the 31'' pipe from the dams to the Rock Creek tributary (see Figure 27). This solution stops the deterioration of key park features because both the amount and the energy of the water flowing to the feature will decrease. However, this solution has no effect on treating polluted stormwater and slowing runoff. The stormwater in the pipe will still be full of sediments and will carry this problem to the Rock Creek tributary. According to the park officials, safety and environmental departments do not permit diverting polluted water to any other body of water. In addition, the NPS cannot apply this solution without disturbing the park's environment.

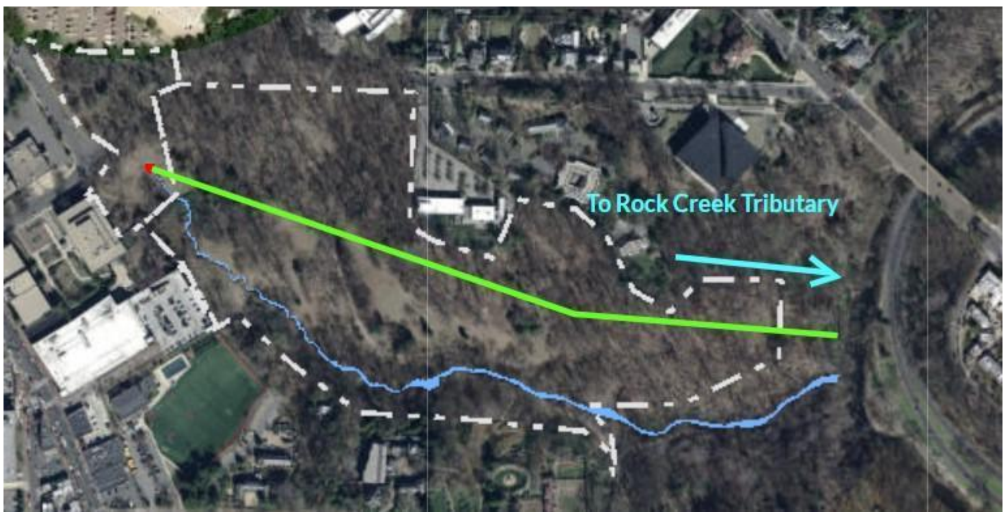

Figure 27: The 31'' pipe outfall (highlighted in red) and the pipe diverting overflow to Rock Creek Tributary (highlighted in green)

Stormwater Ponds: Stormwater ponds help decrease the energy and the amount of water by creating ponds along a stream, and they hinder the flow of the stream. Stormwater ponds do not treat any of the sediments in the stream. According to park officials, the District Department of Environment (DDOE) does not permit this solution in line with a stream.

Regenerative Stormwater Conveyances (RSCs): RSCs control the flow of streams and decrease the sediments by creating weirs, pools, and growing special types of plants (see Figure 28). RSCs are also a solution that could solve both the amount and the energy of stormwater. RSCs would treat the water before it reaches the stream. This solution is applied in several places around Rock Creek Park. However, this solution is not compatible with the topography of the projected area. Although placing the RSC along the stream can stabilize the stream channel, the slope at the streamside is not steep enough for the implementation of an RSC (M. Schley, personal communication, November 6, 2019). Further, the size of the RSC will be too large for construction along streamside and cause significant disturbance to park environment if it needs to handle a 100 year storm event (M. Schley, personal communication, November 6, 2019). In addition, the department of environment and energy (DDOE) does not allow the construction of RSCs along streams (N. Bartolomeo, personal communication, November 6, 2019). Finally, although the slope upstream is possible for the implementation of an RSC (see Figure 29), it is likely too steep for construction (W. Yeaman, personal communication, October 24, 2019).

Figure 28: An example RSC implemented near the stadium in Rock Creek Park

Figure 29: Possible locations for RCS (outlined in blue)

Constructed Wetlands: The final solution we considered is a constructed wetland (see Figure 30). This solution can be effective in controlling the energy and the amount of water in a stream. These wetlands have special types of plants and soil that will capture the sediments in the stream and improve water quality. This solution could blend into the park and provide an aquatic habitat for wildlife. However, it is commonly associated with the increase in mosquito breeding and the unpleasant smell caused by the growth of algae. Because Dumbarton Oaks Park is located in the middle of a residential area, both of these problems should be considered before implementation. Another disadvantage is that the efficiency of the constructed wetland decreases in cold weather.

Figure 30: Example of a constructed wetland (MSU Infrastructure Planning, n.d.)

Solution	Protect park features	Reduce peak discharge	Improve water quality	Disturbance to park environment	Feasibility	Approved by DDOE/DOEE
Piping	Yes	No	No	High	Low	No
Pond	Yes	Yes	No	High	High	No
RSC	Yes	Yes	Yes	Medium to High	Low	In stream: No Upstream: Yes
Constructed Wetland	Yes	Yes	Yes	Low to Medium	High	Permit required

Figure 31: Possible stormwater solutions evaluations

5.0 Recommendations and Conclusions

In this chapter, we recommend a constructed wetland as the stormwater management solution for Dumbarton Oaks Park. We then discuss the design and the implementation of the constructed wetland. Then we recommend the next steps for the National Park Service to construct the wetland.

5.1 A Constructed Wetland for Dumbarton Oaks Park

We recommend the NPS implement a constructed wetland in the project site shown in Figure 32 as the solution for stormwater management in DOP for several reasons.

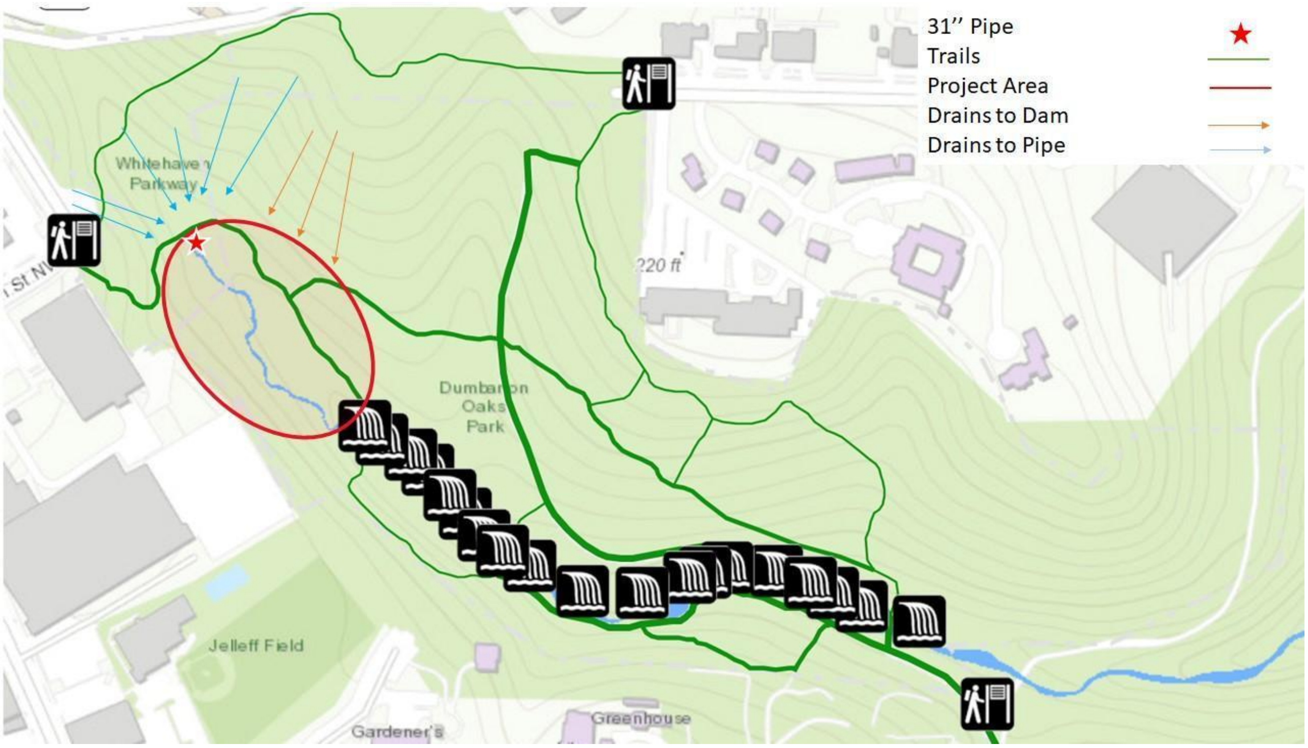

Figure 32: A map of DOP that shows the proposed project site between the 31'' pipe and the first dam

A constructed wetland could provide several benefits to DOP. First, it is a low impact solution that would effectively control the outflow from the main 31'' pipe to the first dam. Also, a constructed wetland could improve the water quality of runoff from the 100 acres drainage area consisting of urban area above DOP (see Appendix F). This solution would likely blend with the landscape and the environment of the park. Figure 33 shows a design of a constructed wetland including the water path and the different types of plants. It could also improve the aquatic habitat in the park.

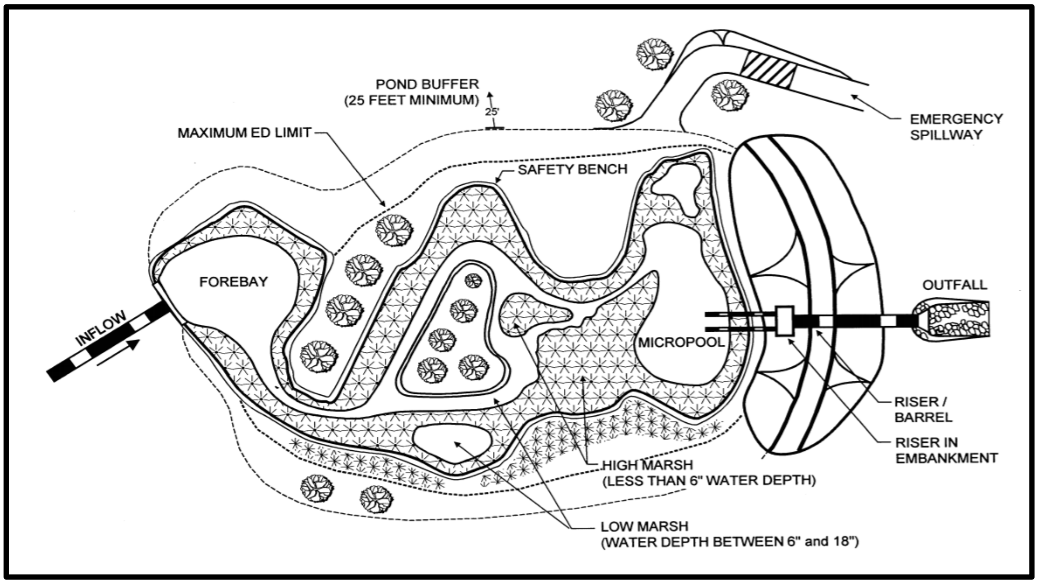

Figure 33: Aerial drawing of one of the possible designs for constructed wetlands
(Pennsylvania Stormwater Management Manual, 2006)

The team suggests that the designed wetland capacity be 30 acre-feet to handle a 100 year storm (see Appendix F). Based on this volume, the depth of the wetland must be at most 6 ft to be efficient in the proposed project area. As shown in Figure 34, the depth of the wetland is the distance between the water surface of the permanent pool and the 100 year storm stage line. According to Matthew Schley, the regional hydrologist, the wetland depth should not exceed 6 ft due to safety concerns. In order to limit flooding of the historical dams, our team recommended the outflow of the wetland must not exceed 4.3 cubic feet per second, the capacity of the smallest dam (Greenhorne & O'Mara, 1999).

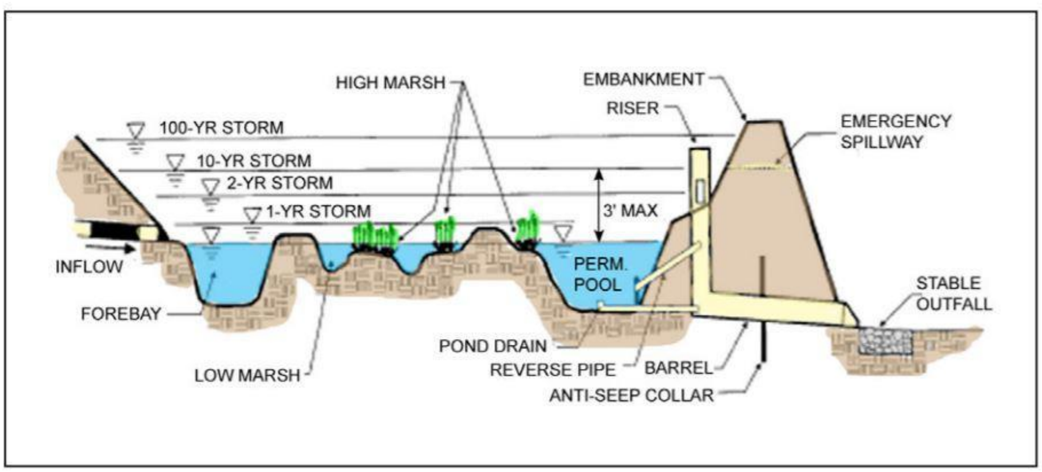

Figure 34: A detailed possible design of the proposed constructed wetland including different storage volumes
(Pennsylvania Stormwater Management Manual, 2006)

Constructed wetlands cause associated challenges to their surrounding area. Two of the most common challenges are mosquito breeding and an unpleasant smell. Both problems result from stagnant water. However, the proposed constructed wetland in DOP receives water from the main 31” pipe that flows continuously during the year. Running water could limit mosquito breeding and the growth of the algae responsible for the unpleasant smell. In addition, controlled and constant water flow could preserve the function of the stream.

5.2 Implementation of the Constructed Wetland

Historical features around the park are one challenge this project faces when creating a construction plan. Getting equipment into the park is not an easy task. The park has two entrances, Lovers Lane and Whitehaven Street. Lovers Lane is located at the Southwest part of the park and is around 1600 feet away from the proposed project site. The Whitehaven Street entrance is located at the Northeast part of the park, and it is around 250 feet away from the project site at a steep slope, 80 feet elevation difference. Our team is recommending the use of Whitehaven Street because it is the closest to the project area and will have the least effect on the historical features.

To implement this solution in the park, the NPS has to get permits for the project, since the project affects both the environment and landscape of the park. The environmental permits are required because of the wetland effect on the stream and the effect on the area surrounding the stream. The landscape permits are required because of the significance of the park and its features.

The Department of Environmental Protection asserts that the wetland construction can be done at any time of the year. However, it is recommended to transplant plants in the period between the early April to mid-June to give the plant a full growing season to set their roots before winter. The constructed wetland will require periodic maintenance from the NPS to maintain its efficiency. This maintenance will usually include: 1. removing the sediment and pollutants from the wetland; 2. Measurement of the outflow to make sure the dams are getting the correct amount of flow; and 3. Inspection of the growth of the plants. During the first three months, the wetland should be inspected every two weeks to make sure the vegetations are growing correctly. During the first three years, the wetland the maintenance should be at least once every three months and after heavy storms. Next, during the first three years, the wetland should be corrected as needed to maintain the required efficiency. Finally, the wetland should be set and only require maintenance every six months and after heavy storms (Department of Environmental Protection, 2006).

Constructed wetlands are cost efficient. Construction cost estimates range between $41,000 to $89,000 for every acre depending on the landwork. Taking in consideration the topography of the project area and the soil types, we believe that a design for the constructed wetland will cost around $500,000 (see appendix G).

5.3 Next Steps for the National Park Service

Going forward, the NPS needs more accurate soil data for the project site. They have to perform soil tests to accurately identify the soil types and infiltration rates in the proposed area. To calculate an accurate wetland volume, the NPS will have to measure the base flow rate, the peak discharge of the 31'' pipe, and the amount of water draining to the project site. Our calculations were limited by time and resources.

Starting in 2013, large development projects that disturb land and trigger DC's stormwater management regulations require the installation of green infrastructure (GI) to reduce runoff (DC Stormwater Management Regulations). While each project must meet at least 50% of the Stormwater Retention Volume (SWRv) which is on-site runoff volume produced by a 1.2 inches storm, Department of Environment and Energy (DOEE) offers flexibility to meet the remaining 50% offsite through the use of Stormwater Retention Credits (SRCs). SRCs are generated when regulated projects achieve retention volume exceeding the regulatory requirement (SWRv) or voluntary stormwater retrofits expand the pre-project retention volume. In each case, retention volume beyond the SRC ceiling, which is runoff volume produced by a 1.7 inches storm, will not count. One SRC equals to one gallon of additional retention volume for one year (Center for Watershed Protection, 2013).

The proposed solution in Dumbarton Oaks Park as a voluntary stormwater retrofit will generate 1,870,000 SRCs per year, and DOEE will certify up to 3 years' worth of SRCs at one time (Center for Watershed Protection, 2013) with 5,600,000 SRCs and total open market value of $10,400,000 (See Appendix H). These SRCs can then be sold directly to DOEE by signing a SRC purchase agreement (SRC price lock program) or sold to project developers via open market for compliance with their off-site retention requirement.

The National Park Service must acquire all of the permits needed before the implementation of this project to protect the historical value of Dumbarton Oaks Park. Permits include: 1. The US Army Corps of Engineers, permit 404. 2. The District of Columbia Sediment and Erosion control. 3. NPS Special Use Permit (N. Bartolomeo, personal communication, December 5, 2019). Finally, the NPS should consult with the landscape architect regarding the effect of the constructed wetland on the features both functionally and aesthetically.

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Appendices

Appendix A: Interview Preamble

Hello, we are a group of Worcester Polytechnic Institute (WPI) students working for the National Park Service in Washington DC. We are currently working in Rock Creek Park trying to propose a solution for the stormwater problem in Dumbarton Oaks Park. We are hoping to ask you a few questions pertaining to our project and Dumbarton Oaks Park. You do not have to answer anything you do not want to, and your answers can remain confidential and anonymous if you would like. Thank you for your help.

Appendix B: Interview Script for Nick Bartolomeo, Chief of Resource Management.

- How long have you been working for the National Park Service?
- What do you do as Chief of Resource Management?
- Is there anything that stands out about Dumbarton Oaks?
- How long has Dumbarton Oaks been facing excessive stormwater and erosion?
- What damage would you say is the most significant or a major concern we should focus on?
- What steps have been taken over the years to manage the land?
- What would you like to see from us at the end of this project? What would characterize a successful project?
- Should we focus on flow and volume of water or managing erosion? Western or eastern?

Appendix C: Interview Script for Mike McMahon, Landscape Architect.

- How long have you been working for the National Park Service?
- What got you into landscape architecture?
- What do you do as the landscape architect for Dumbarton Oaks Park?
- Can you tell us a little bit about the cultural and historic value of the park?
- We are trying to propose a stormwater management solution for the park with minimal impact on the cultural and historic value Beatrix Farrand created. What should we consider as we pose a solution?
- As we have read in the hydrology report, some stormwater mitigation measures within the park require modification and reconstruction of park features. Do you consider this an adverse impact on the integrity of the cultural landscape?

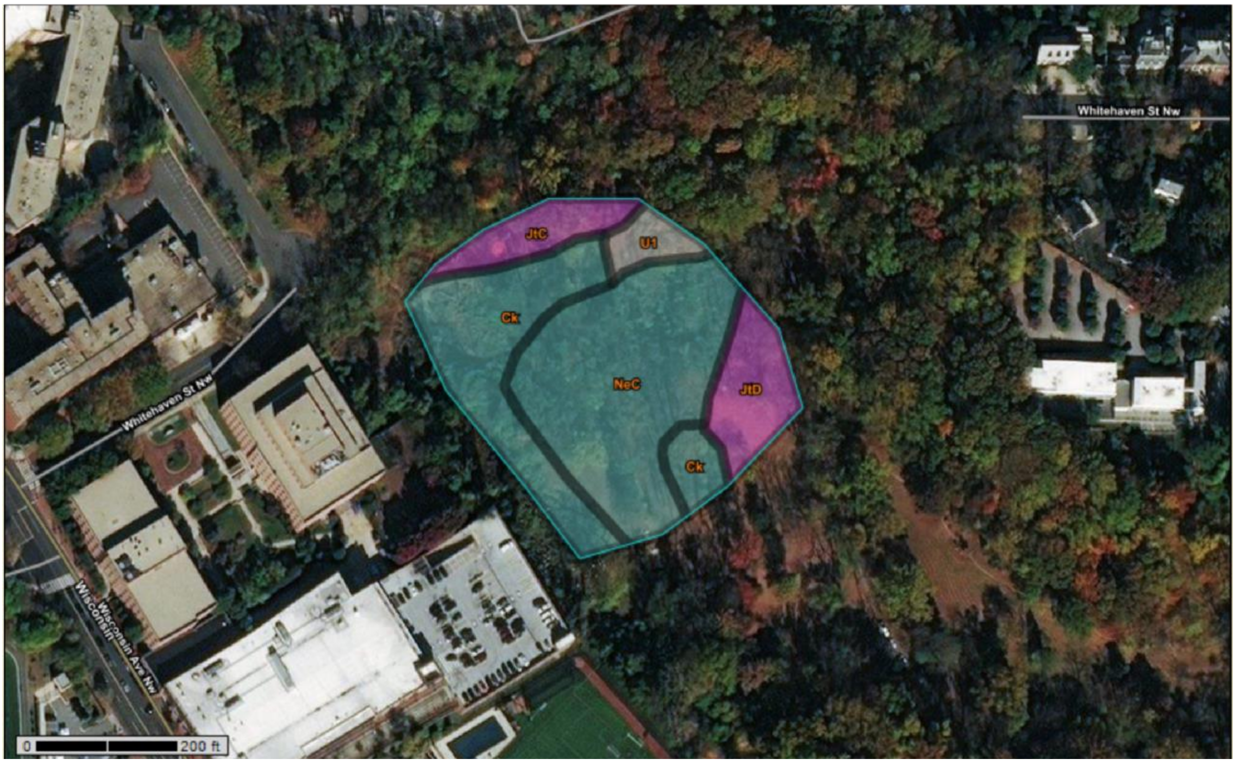
Appendix D: Key Assumptions

- The drainage area, generated by the DOPC web GIS, for the first dam will be our area of interest (67.47 + 32 = 99.47 Acres).
- All impervious areas within our area of interest are considered directly connected to drainage systems.
- Storm sewer only handles a small portion of runoff volume and discharge during a large event (USDA, 1986).
- All estimations are based upon a type II 24h, 100 year storm.
- The soil type was assumed based on the online tool "Web Soil Survey".
- All land cover types and Hydrologic Soil Group (HSG) characterizations for the drainage area assume the solution has not yet been implemented.

Appendix E: Soil Types and Map

According to an online soil survey, below is a map of the project area we are studying divided by soil type (WebSoilSurvey, 2019). The table presents the size and percentage of each type of soil and its rating group. As explained in the figure below, 75.6% of the project area is silt (blue) and 21.1% of the project area is sand (pink).

Rating groups represent the infiltration rate. Group A has a higher infiltration rate, while group C has a lower one.



Tables — Hydrologic Soil Group — Summary By Map Unit

Summary by Map Unit — District of Columbia (DC001)

Summary by Map Unit — District of Columbia (DC001)

Map unit symbol	Map unit name	Rating	Acres in AOI	Percent of AOI
Ck	Codorus silt loam	C	1.3	31.6%
JtC	Joppa gravelly sandy loam, 8 to 15 percent slopes	A	0.4	8.5%
JtD	Joppa gravelly sandy loam, 15 to 40 percent slopes	A	0.5	11.3%
NeC	Neshaminy silt loam, 8 to 15 percent slopes	C	1.9	44.0%
U1	Udorthents		0.2	4.5%
Totals for Area of Interest			**4.3**	**100.0%**

Appendix F: Watershed and Flow Calculations

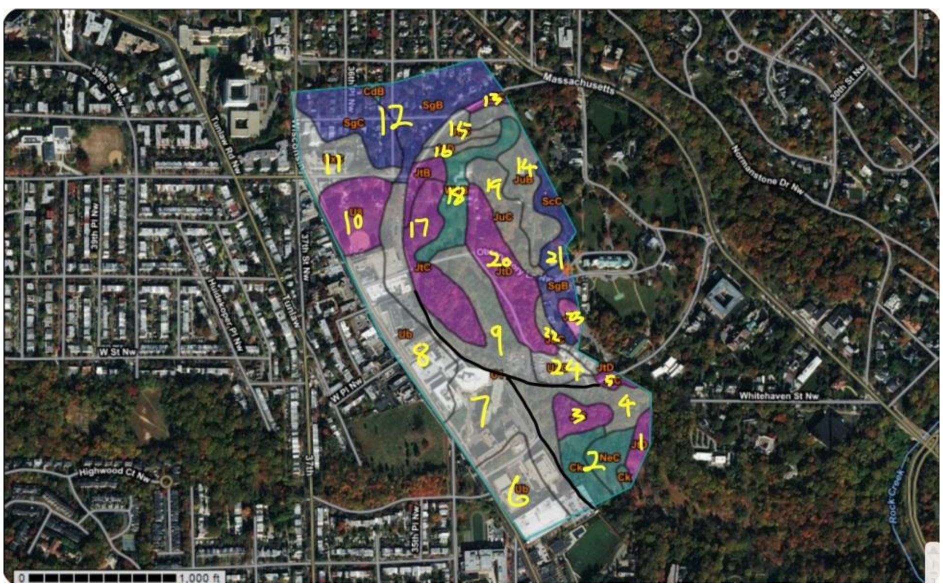
Watershed Map:

The green line outlines the drainage area for the first dam (99.5 acres), and it was obtained by using the “Calculate Drainage Area” function for area of interest drawn at the first dam in the DOPC web GIS (67.5 acres). Then, it was combined with known watershed data (another 32 acres).

HSG Map:

The hydrologic soil group map was obtained from the NRCS Web Soil Survey by drawing the area of interest following the outline of the total drainage area.

Sub Areas:



The entire watershed was subdivided into 24 labeled areas with different hydrologic soil groups or cover types for imperviousness and runoff estimation.

HSG chart for the drainage area:

Ck	Codorus silt loam	C	2.6	2.6%
JtB	Joppa gravelly sandy loam, 0 to 8 percent slopes	A	1.2	1.3%
JtC	Joppa gravelly sandy loam, 8 to 15 percent slopes	A	8.3	8.6%
JtD	Joppa gravelly sandy loam, 15 to 40 percent slopes	A	7.5	7.7%
JuB	Joppa-Urban land complex, 0 to 8 percent slopes		4.3	4.5%
JuC	Joppa-Urban land complex, 8 to 15 percent slopes		5.8	6.0%
JuD	Joppa-Urban land complex, 15 to 25 percent slopes		0.8	0.8%
NeC	Neshaminy silt loam, 8 to 15 percent slopes	C	2.0	2.1%
ScC	Sassafras gravelly sandy loam, 8 to 15 percent slopes	B	2.0	2.1%
SgB	Sassafras-Urban land complex, 0 to 8 percent slopes	B	8.5	8.8%
SgC	Sassafras-Urban land complex, 8 to 15 percent slopes	B	5.2	5.3%
U1	Udorthents		22.5	23.2%
U8	Udorthents, sandy, smoothed	A	4.3	4.4%
Ub	Urban land		11.9	12.3%
UoC	Urban land-Joppa complex, 0 to 15 percent slopes		1.6	1.6%
UxC	Urban land-Sassafras complex, 8 to 15 percent slopes		4.4	4.5%
WpB	Woodstown-Urban land complex, 0 to 8 percent slopes	C	3.9	4.0%

Assumptions for uncategorized soil

As shown in the Sub Areas map, sub areas 4, 6, 7, 8, 9, 11, 14, 15, 16, 19, 22, 24 has soil types with undetermined hydrologic soil groups.

In order to proceed with runoff volume and peak discharge estimations, the HSGs of undetermined soil types were assumed based upon descriptions in the 1976 Soil Survey of District of Columbia.

Soil type	**Description**	**Assumed HSG**
JuB	medium to rapid runoff	C
JuC	rapid runoff	D
JuD	water capacity is low in relatively undisturbed areas	C
U1	poorly drained to somewhat excessively drained	C
Ub	more than 80% is covered by impervious surface	D
UoC	medium to rapid runoff	C
UxC	Rapid runoff	D

HSG and cover type summary:

The runoff curve number (CN) for each sub area is obtained from Table 2-2a: Runoff curve numbers for urban areas from the USDA 1986 Technical Release 55. Then the runoff curve numbers are weighted to obtain the Weighted CN for runoff volume and peak discharge estimation for the entire watershed. The Weighted CN (ranging from 40 to 98) describes the runoff potential of the watershed and a higher CN results in more runoff produced during a storm. The Weighted CN for the watershed is 78.4 and the CN used in following calculations is 78.

Sub Area No	HSG	Cover Type	Curve Number	Area (acre)	Curve Number X Area
1	JtD-A	Open Space - Poor Condition	68	1.14	77.3
2	Ck&NeC-C	Open Space - Poor Condition	86	3.42	294
3	JtC-A	Open Space - Poor Condition	68	0.888	60.4
4	U1-C	Open Space - Poor Condition	86	3.51	301
5	JtC-A	Open Space - Fair Condition	49	0.292	14.3
6	Ub-D	Roofs and Driveways	98	5.53	542
7	U1-C	Roofs and Driveways	98	11.9	1160
8	Ub-D	Roofs and Driveways	98	5.87	575
9	U1-C	Open Space - Good Condition	74	6.54	484
10	U8-A	Open Space - Fair Condition	49	4.49	220
11	UxC-D	Roofs and Driveways	98	3.79	372
12	SgC&SgB-B	Town Houses	85	12.7	1070

13	JtC-A	Open Space - Good Condition	39	0.162	6.32
14	JuB-C	Open Space - Good Condition	74	4.62	342
15	JuC-D	Open Space - Good Condition	80	1.27	102
16	JuD-C	Open Space - Good Condition	74	0.553	40.9
17	JtB & JtC-A	Open Space - Good Condition	39	7.46	291
18	WpB-C	Open Space - Fair Condition	79	2.98	235
19	JuC-D	Open Space - Good Condition	80	2.22	177
20	JtD-A	Open Space - Good Condition	39	3.95	154
21	ScC & SgB-B	Open Space - Fair Condition	69	6.87	474
22	JuC-D	Open Space - Fair Condition	84	1.20	101
23	JtD-A	Roofs and Driveways	98	1.07	105
24	UoC-C	Parking Lot	98	1.78	174
Total				94.1	7380
Weighted Curve Number					78.4

Flow Path Chosen to estimate Time of Concentration:

The flow path (highlighted in green) that aligns with the eastern boundary of the drainage area of the first dam is chosen to estimate the time of concentration (Tc) for the watershed. This is the time it takes for runoff to travel from the hydrologically most distant point to the point of interest. The flow path is chosen for two main reasons: 1) The path is likely to have the greatest linear distance (4610 ft) over other flow paths within the watershed. 2) A large portion of this flow path passes through the lawns in the Naval Observatory and Dumbarton Oaks Park, which have large coefficients of roughness (Manning's n) and is likely to result in the longest travel time.

Limitations:

The assumed flow path accounts for the effect of storm sewers upon the Tc for the watershed by assuming a segment of the entire path as concrete pipe. The estimated Tc might be longer than the actual situation where the effect of storm sewer is more significant, resulting in an underestimation of the peak discharge at the first dam. More detailed studies on the flow patterns in the watershed during storm events with respect to storm sewer is required for more accurate Tc and peak discharge estimation.

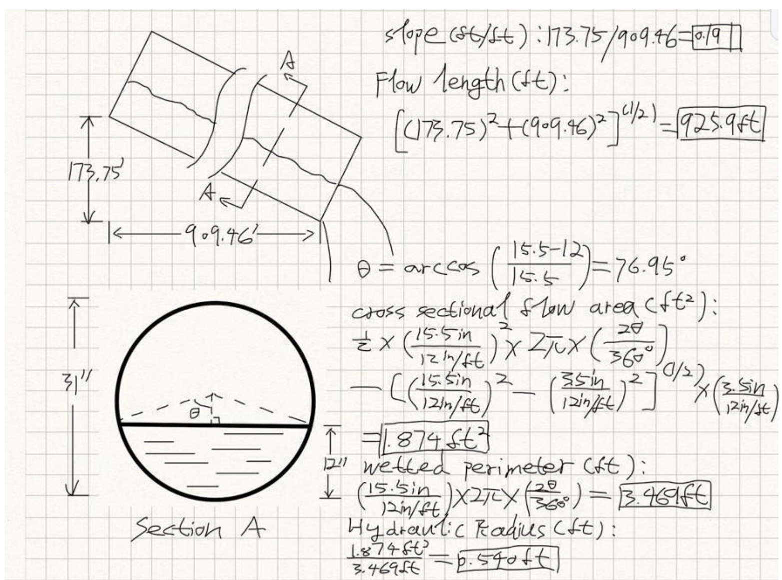
Flow Characterization and Calculations:

The following calculations employ the velocity method documented in the 1986 USDA TR-55. The assumed flow path is divided into segments of different flow characteristics. Tc is obtained by summing up travel time through each of the sub-segments. The Win-TR55 computer program is used to assist calculation (USDA, 1986).

The first 100 ft of the assumed flow path (highlighted in orange) is assumed to be sheet flow, with an average slope of (10ft / 177.413ft) = 0.056. Since the segment flows through a residential area, the roughness coefficient is assumed to be 0.011 for smooth surfaces (concrete, asphalt, gravel or bare soil). The resulting travel time is 0.013 hour.

After the first 100ft, sheet flow usually becomes shallow concentrated flow (1986 USDA TR-55). The segment of the assumed flow path after the first 100 ft and before entering the park valley (highlighted in red) is assumed to be shallow concentrated flow, with a flow length of $(3580^2 + (291 - 261)^2)^{(½)}$ = 3580ft. And with an average slope of (291 - 261)/3580 = 0.00830. The surface condition is unpaved, and the result travel time is 0.676 hour.

According to suggestions from the regional hydrologist Matthew Schley, after entering the park valley, the flow (highlighted in purple) is assumed to continue as open channel flow with water depth of 12’’ in a 31’’ concrete pipe until it reaches the first dam. The flow length is $(910^2 + (298 - 124)^2)^{(½)}$ = 9260 ft. The average slope is (298 - 124) / 910 = 0.191. The Manning’s n for concrete is 0.011 according to the engineering toolbox website and the result travel time is 0.00700 hour.



Above are diagram showing the slope of the pipe and cross-sectional view of the pipe with the depth of flowing runoff and its cross-sectional flow area and wetted perimeter calculated for speed and travel time estimation.

Sub-area Name: First Dam | Rename | Clear

2-Year Rainfall (in): 3.16

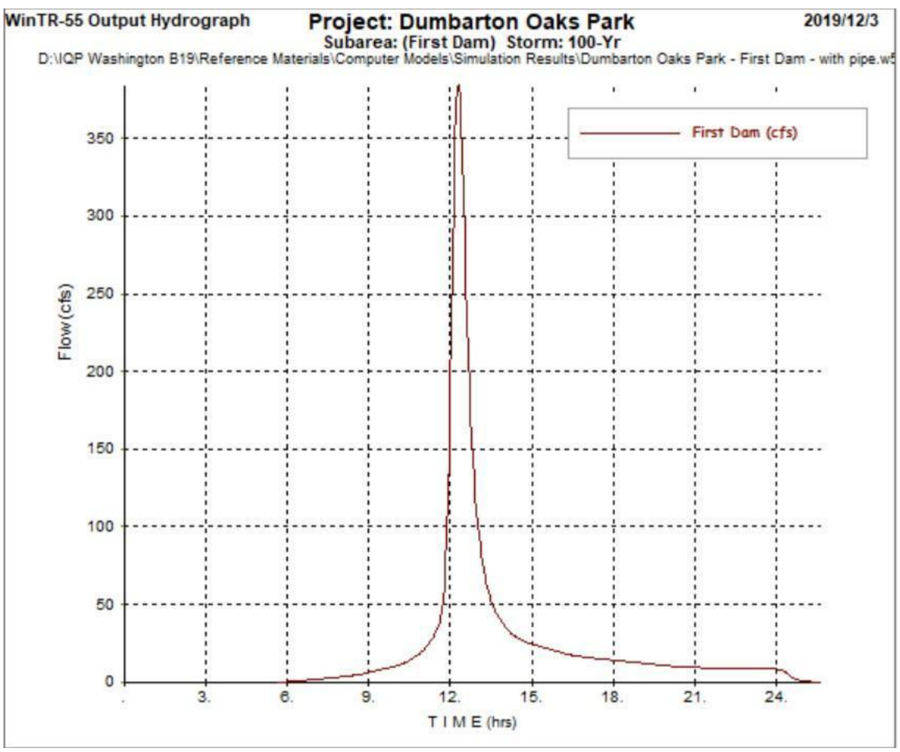
Time of Concentration Details

Flow Type	Length (ft)	Slope (ft/ft)	Surface (Manning's n)	n	Area (ft?	WP (ft)	Velocity (f/s)	Time (hr)
Sheet	100	0.0560	Smooth Surface (0.011)					0.013
Shallow Concentrated	3579	0.0083	Unpaved					0.676
Shallow Concentrated								
Channel	926	0.1910		0.011	1.87	3.47	36.746	0.007
Channel								
Total	4,605						1.8379	0.696

Above is a summary of Tc details for the watershed. The Tc estimated is 0.696 hour.

Hydrographs and peak discharge:

By running WinTR-55, for a 100 year -24 hour storm, the peak discharge at the first dam happens 12.3 hours after the start of the storm, which is 385 cfs.



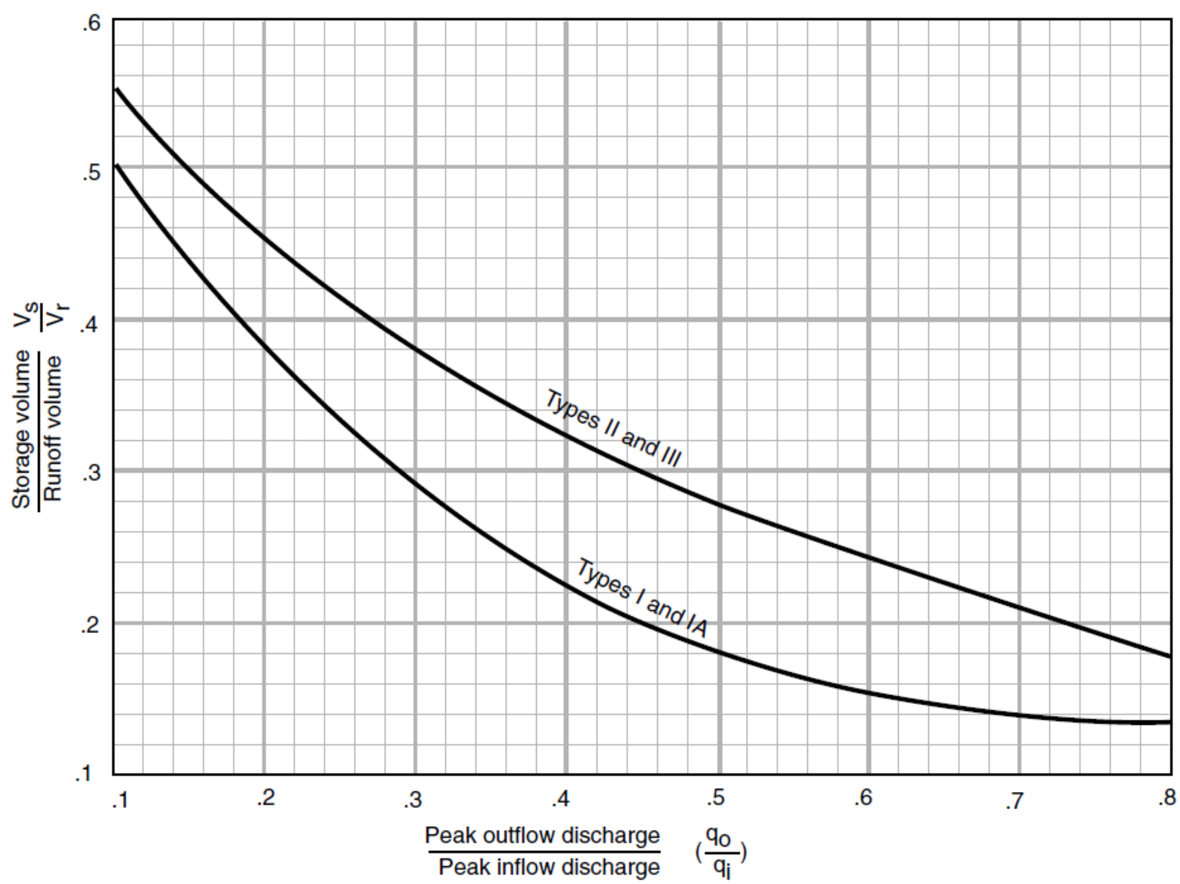
Discharge hydrograph at first dam

Runoff and Storage Volume:

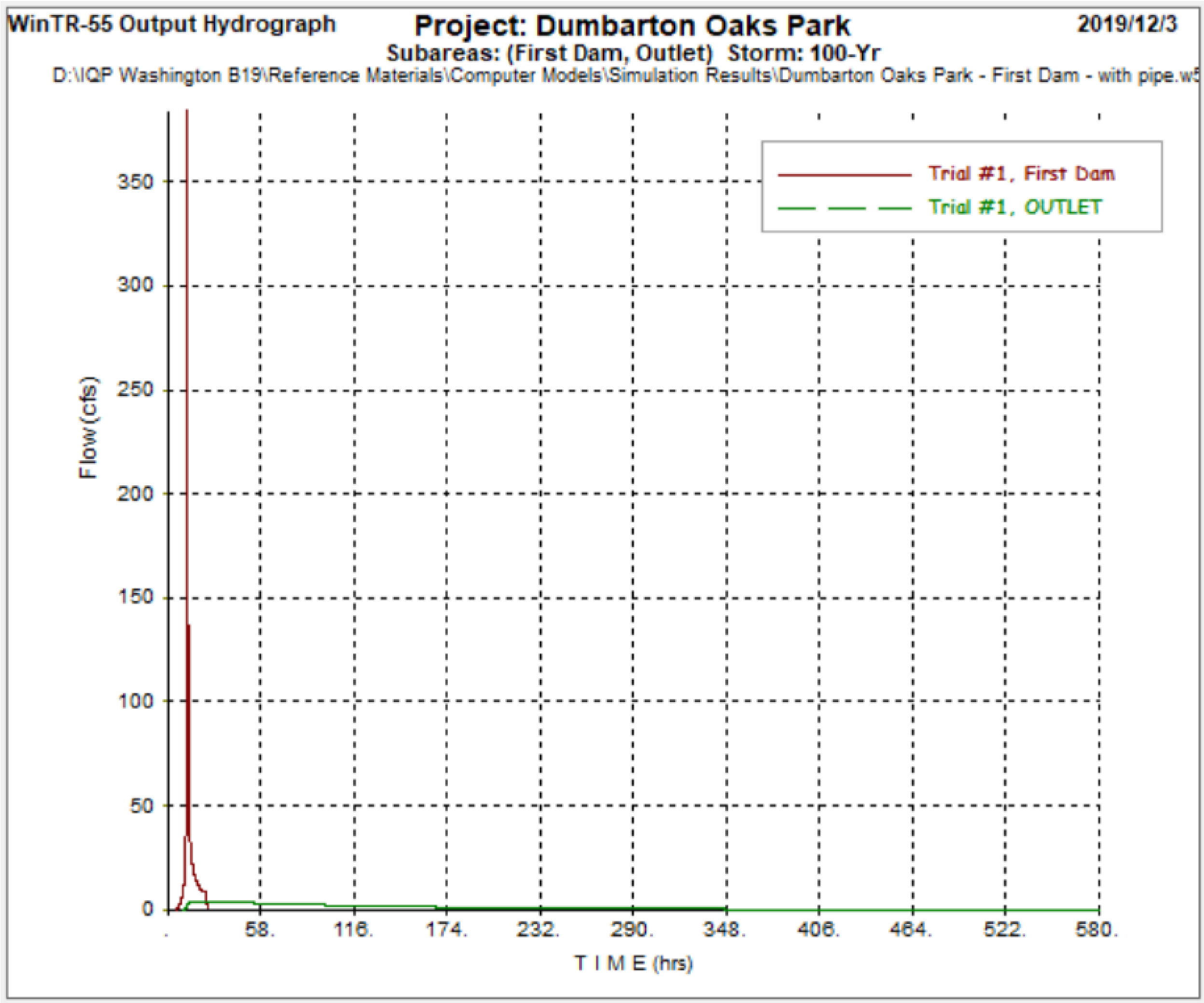
A 100 year, 24h storm will generate about 45 acre-feet of runoff. If the goal of the solution is to limit outflow discharge to 4.3 cfs (capacity of the west laurel fall, Phase I hydrologic survey, Greenhorne & O'Mara), the required storage volume for the solution will be about 30 acre-feet. Assuming the area for the project site to be 5 acres, the average depth for the solution will be 6 feet.

100 year 24h rainfall (in)	8.37
Runoff (in)	5.79
Runoff (acre - feet)	45.4
100 year 24h peak discharge (cfs)	385
Downstream discharge limit (cfs)	4.30
TR-55 Storage Volume (acre - feet)	30.2
Area for solution (acre)	5.00
Average Depth for solution (feet)	6.05

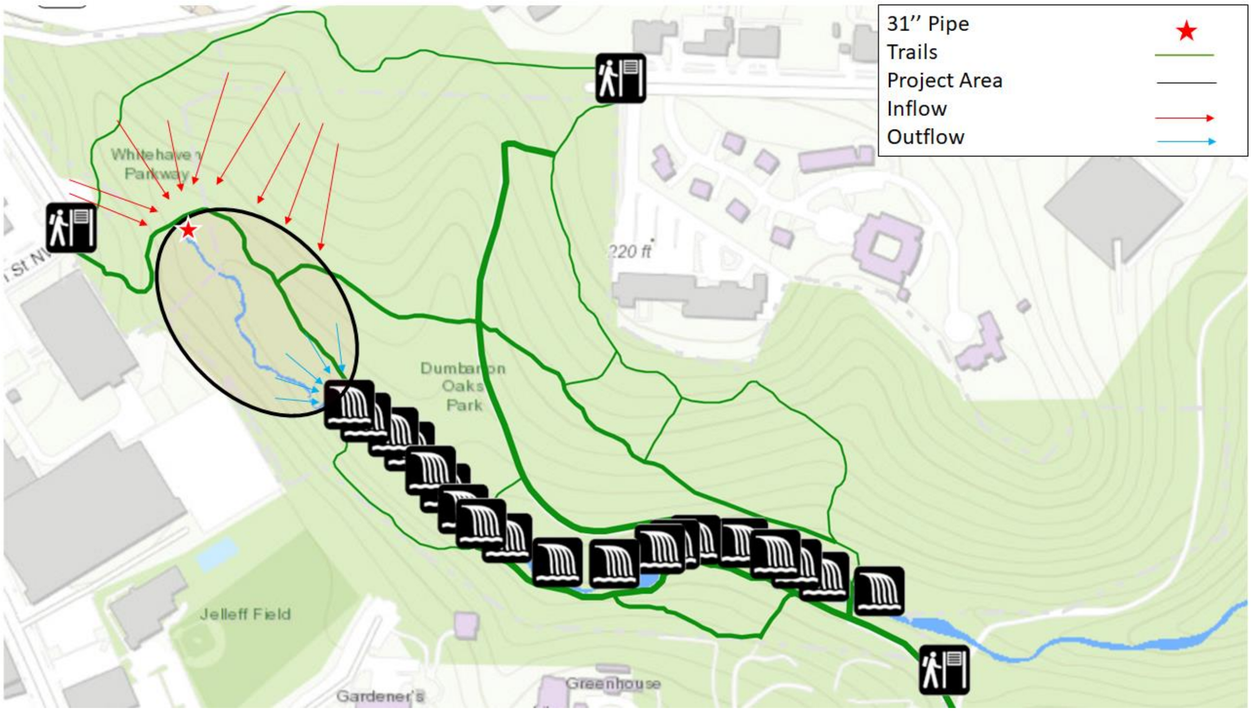
According to chapter 6 of the USDA 1986 TR-55, The required storage volume for the solution is determined by the type of rainfall, total runoff volume, and the ratio between the peak inflow and outflow rates.



The graph above shows the relation between the storage to runoff volume ratio and the peak inflow to outflow ratio for different types of rainfall (USDA, 1986). As illustrated in the graph, larger storage volume is required for more peak discharge reduction.



The hydrograph above shows the solution's effect on peak discharge reduction. The red line indicates the discharge before entering the solution, and the green line indicates discharge at the outlet of the solution. The solution delays peak discharge from 12.3 hour to 24.5 hour after the storm starts and reduces peak flow from 385 cfs down to 4 cfs.

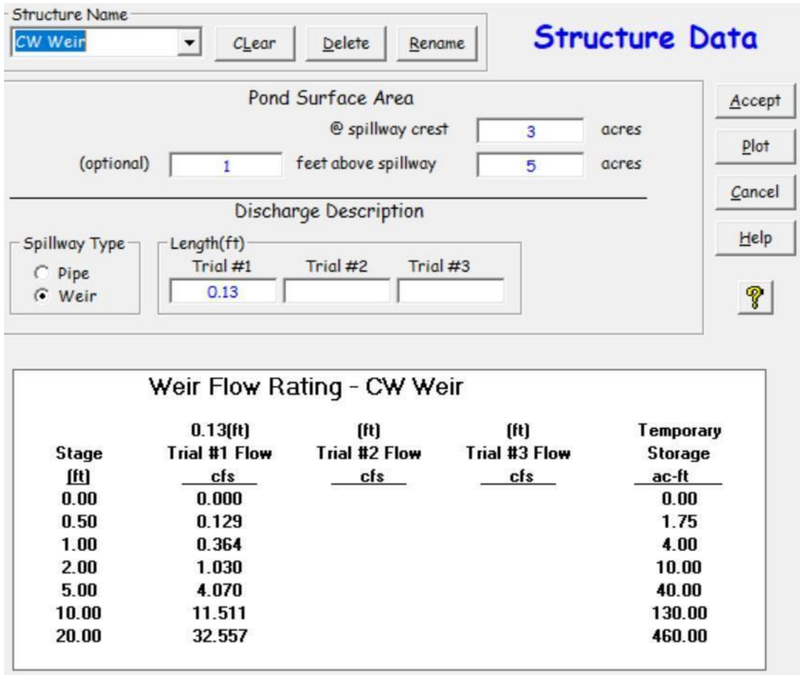


Above is a map showing the location of the solution (outlined in black). Runoff flowing overland and in the pipe drains into the solution as indicated by the red arrows. The solution captures the runoff and discharges the mitigated flow downstream, as indicated by the blue arrows.

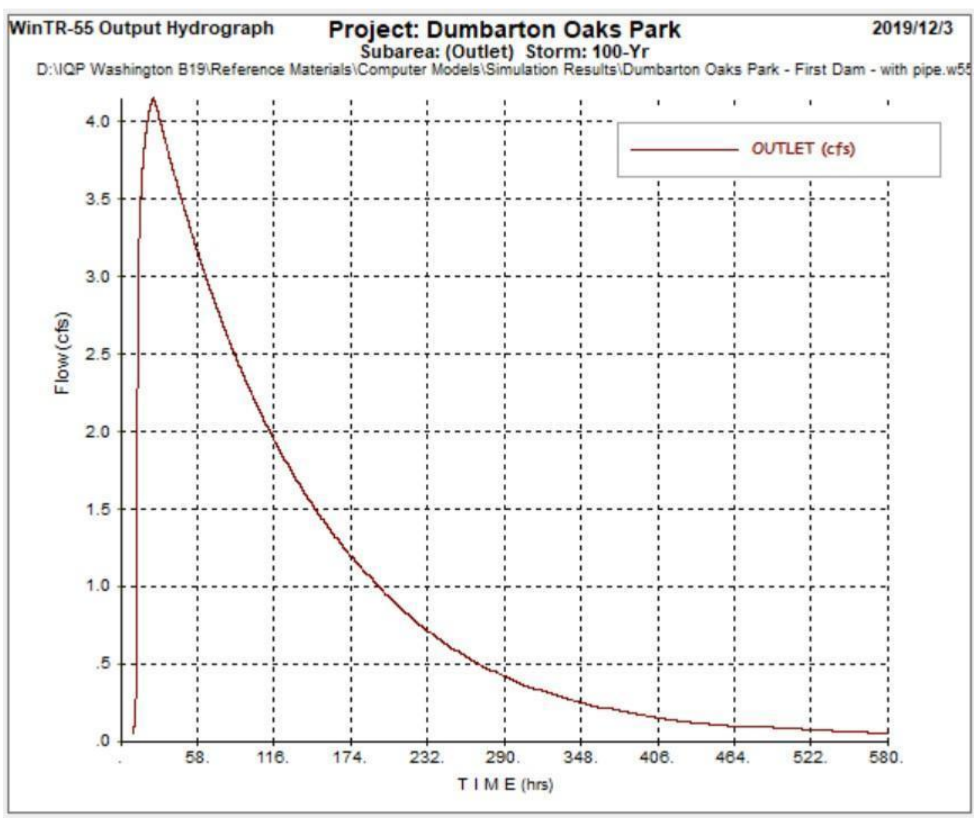
Outflow Structure

Assuming the pond area at the spillway crest is 3 acres and the area 1 foot above the spillway crest to be 5 acres, and also assuming the outflow structure as a broad crested weir with a crest length of 0.13, the peak discharge will decrease to 4.16 cfs and occur 24.5 hours after the start of a 100 year, 24 hour storm.

While the specifications of the pond and weir are obtained by iteratively adjusting the parameters and comparing the peak discharge with the desired limit (4.3 cfs), observations suggests that shorter spillway crest length and larger increment in pond area per foot above the crest contribute to lower peak discharge.



Specifications of the outflow weir



Discharge hydrograph at the outlet of the solution

Appendix G: Wetland Estimated Cost Calculations

The average capital cost is between $30,000 to $65,000 for every acre (Pennsylvania Stormwater Management Manual, 2006).

Based on our information of the topography and the soil types we predict our design for our design for the wetland to at the higher end, $65,000 per acre.

Due to the age of the paper we have to account for inflation.

$65,000 in 2004 is equal to $89,000 in 2019.

The project area is 5 acres.

The estimated capital cost = The project area * the average cost = $89.000*5 = $450000
Taking in consideration the depth of the wetland, 6 ft, and the introduction of clay into the soil, our team is estimating the total cost to be $500,000.

Appendix H: Stormwater Retention Credits (SRCs) and Total Value Estimation

The estimation was done based upon these four assumptions

1. The solution captures and treats runoff from the same drainage area in appendix F.
2. The solution should be able to fully contain runoff volume produced by a 1.7 inch storm.
3. The only cover types present in the area are impervious covers and natural covers.
4. The retention effect of pre-existing retention facilities within the area is neglected. Which means SRC equal to ceiling retention volume.

The "DOEE SRC Purchase Price" is the first 6-year purchase price for Non-Tidal MS4 (Municipal Seperate Storm Sewer) sewershed obtained from the "SRC Price Lock Program" page from the DOEE government website.
The "2019 Average SRC Sale Price" is obtained from the DOEE Stormwater Database website.

DOEE SRCs	Value
Ceiling rainfall (in)	1.70
Percent of Impervious cover	45.2
Runoff Coefficient for Impervious cover	0.95
Percent of compacted cover	0
Runoff Coefficient for compacted cover	0.25
Percent of natural cover	54.8
Runoff Coefficient for natural cover	0
Total area (acre)	94.1
Total area (ft^2)	4,100,000
Ceiling retention volume (acre - feet)	5.73
Ceiling retention volume (gallon)	1,870,000
1 year worth of SRCs	1,870,000
3 year worth of SRCs	5,600,000
DOEE SRC Purchase Price ($)	1.95
2019 Average SRC Sale Price ($)	1.86
SRC Total Value - DOEE - 1 year ($)	3,640,000
SRC Total Value - DOEE - 3 year ($)	10,900,000
SRC Total Value - Open Market - 1 year ($)	3,470,000
SRC Total Value - Open Market - 3 year ($)	10,400,000

Above is a table summarizing site information, SRC and total value estimations.