FOREST THEATRE DAYLIGHTING PROJECT

Joseph Britton Hill

A Technical Report submitted in partial fulfillment of the requirements for the degree of Master of Science in Environmental Engineering in the Department of Environmental Sciences and Engineering of the Gillings School of Global Public Health at the University of North Carolina at Chapel Hill

Chapel Hill

2016

Approved by:

Dr. Pete Kolsky

Dr. Glenn Walters

Ms Sally Hoyt

ABSTRACT

Joseph Britton Hill: Forest Theatre Daylighting Project

(Under the direction of Dr. Pete Kolsky)

Daylighting is an urban drainage design concept that converts a stormwater culvert into an open channel to improve stormwater management, water quality and reduce peak runoff volumes. Daylighting streams on the UNC campus can also assist the University's goal of reducing nutrient runoff to Jordan Lake.

This report analyzes the options for daylighting a 450-foot section of stormwater drainage pipe near the Forest Theatre on the University of North Carolina- Chapel Hill campus. The pipe discharges into Battle Branch Creek which empties into Bolin Creek eventually draining into Jordan Lake. This project analyzes alternative methods to transport the stormwater through the area, assesses the environmental and hydrologic benefits of these alternatives and determines the ecological benefits of a daylighted stream as compared to the current stormwater drainage culvert. An implementation plan was developed and total project costs were compared to the present value of future benefits.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

BMP	Best Management Practice
CFS	Cubic Feet per Second
EPA	United States Environmental Protection Agency
ESD	Energy Services Department of the University of North Carolina at Chapel Hill
EHS	Environmental Health and Safety Department of the University of North Carolina at Chapel Hill
EGL	Energy Grade Line
HGL	Hydraulic Grade Line
NCDEQ	North Carolina Department of Environmental Quality
NCDENR	North Carolina Department of Environment and Natural Resources
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NPV	Net Present Value
RK&K	Rummel, Klepper and Kahl, LLC
SCS	Soil Conservation Service
SWMM	Stormwater Management Model
TN	Total Nitrogen

TP	Total Phosphorus
TSS	Total Suspended Solids
UNC	University of North Carolina at Chapel Hill
USACE	United State Army Corps of Engineers

CHAPTER 1: INTRODUCTION

This report describes: the rationale for daylighting the Forest Theatre section of stormwater drainage; the hydrologic and environmental benefits of daylighting; and the engineering design options necessary to safely transport storm events. It describes in detail the design options, analyses of each option and the criteria used to determine the optimal solution. This report also presents implementation details of the chosen design, including costs, nutrient reduction benefits, permitting, schedule of construction and a cost-benefit analysis of the chosen design.

Daylighting

Daylighting is a design technique used to return a stream to its natural form by bringing a piped, underground stream to the land surface. The purpose of this is multidimensional- stormwater that would have been delivered to a stream at a high velocity through a culvert will be moving at a reduced rate in daylighted sections due to the channel lining- grass, rock or a combination of the two- creating a higher resistance thus reducing the velocity. The reduced velocity will allow sediment to settle and runoff to infiltrate into the soils. These natural features mimic the functions of a free-flowing stream that were lost through containing the stormwater in a culvert. As more focus is being put on water quality management, daylighting is becoming a more common urban development practice.

Nutrient Credits

In addition to the potential environmental benefits of daylighting, the University is also interested in the benefits of nutrient "credits" from the North Carolina Department of Environmental Quality (NCDEQ). NCDEQ assesses nutrient reduction efforts in two contexts, new development and existing development. The Battle Branch Daylighting project is located on a site classified as “an existing development” as the site has been altered from its original state and contains infrastructure (Jordan Water Supply Nutrient Strategy 2007).

The Forest Theatre project area is located in the Upper New Hope sub-watershed of the Jordan Lake nutrient strategy watershed which is a large-scale, long term watershed restoration site as defined by NCDEQ. The Jordan Lake nutrient strategy aims to reduce both point and nonpoint sources of pollution across the watershed.

A nutrient market functions by establishing a mandatory cap on the combined pollution loads from point sources. This process utilizes the fact that when areas are developed there are various environmental precautions that can be taken during development and each option has the potential to affect the volume of sediment and nutrient loading coming from that development (*Houtven et al.* 2012). The differences in costs occur due to myriad factors ranging from an individual source’s production processes to its location or size to available technologies for reducing the load (Maryland Nutrient Credits). The generator of the credits can then sell these credits to relatively high-cost sources, allowing the purchaser to “reduce” its load at less cost (*Houtven et al.* 2012). For this project, the State of Maryland and the Energy Services Department of the University of North Carolina-Chapel Hill (ESD) will be referenced as a basis for estimating the magnitude and value of nutrient credits.

Forest Theatre

The Forest Theatre is located within the drainage basin of this project and is of noteworthy historical value to the area. It was constructed in 1918 and is registered on the Chapel Hill National Register Historic District. This outdoor, hillside theatre is level three in historical significance meaning that the complete structure, interior and exterior, is historically and architecturally significant (Forest Theatre Preservation Survey). The theatre is still used for plays and concerts from approximately May until October.

Figure 2: Forest Theatre Watershed on the UNC main campus. (Source: Google Earth, 2015).

Forest Theatre has a gravel parking lot, Lot N5, with a total of 15 vehicle spaces. Fourteen spaces are referred to as “non-gated spaces” and one is a reserved space (UNC-Parking, 2015).

Flooding of the theatre is not a high priority for ESD. Forest Theatre does occasionally flood but it is thought that is due to the drainage infrastructure of the theatre and not a result of stormwater overflow (Personal Communication, Sally Hoyt 2015).

Previous Modeling

The design analysis will utilize the model “2013 SWMM Model Documentation: Cole Springs, Battle Branch and Friday Center; Stormwater Master Plan, Phase II” completed by the engineering firm Rummel, Klepper and Kahl, LLC (RK&K). The model created by this study will serve as a basis for the SWMM modeling of this daylighting project. The Phase II model provides detailed hydrologic information needed for the Forest Theatre area such as existing stormwater infrastructure, and pervious and impervious surfaces. A walking inspection of the project area was conducted and the infrastructure detailed in the model seems to be accurate at this time. The UNC Master Development plan also stated no major development and/or construction in this sub-watershed is anticipated in the foreseeable future.

Site Characteristics

The Forest Theatre project area is part of a catchment basin that drains approximately 49.3 acres of the northeastern section of UNC's main campus. The watershed's location can be seen in Figure 1. The blue region represents the total watershed area with the Forest Theatre subcatchment displayed in orange. Currently, the physical characteristics of the land are open lawn with interspersed mature oak and sweetgum trees that are bisected by a crushed gravel walking path approximately 300 feet long. This open lawn area sits upstream of the Forest Theatre and its vehicle parking lot. The discharge pipe's outlet is on the eastern side of the parking lot.

Design Constraints	
Watershed Area	49.3 acres
Length of Pipe to be Daylighted	346 ft
Predominant Soil Type	Appling sandy loam

Table 1: Site characteristics that constrain design

The current drainage system layout is shown in Figure 2 and the specifications for each conduit are shown in Table 2. These conduits will be redesigned within the project reach. The project area is broken up into two reaches: one upstream and one downstream of additional flow that arrives from the south. This additional flow adds approximately 25% of the combined flow that is transported through the lower reach. Additionally, as Table 2 shows, there is a change in slope for the lower reach; therefore, these two reaches will be identified separately throughout this report.

Figure 2: Current Layout of Forest Theatre Stormwater Discharge Piping System (Source: 2013 SWMM Model Documentation, RK&K).

SWMM Name	Length, ft	Diameter, ft	Shape	Slope
Upper Reach	194	2.5	Circular	2.5%
Lower Reach	264	2.5	Circular	2.3%

Table 2: Descriptions of Existing Conduits in Battle Branch Daylighting Project Reaches

Stormwater flows for a 24-hour, 10-year event were modelled for the current conditions of the infrastructure because this is the design standard of the ESD. Peak conditions are shown in Table 3. Simulations show that this section of stormwater drainage does not flood during this design event with the current layout. The purpose of this report is to analyze the option of implementing an alternative stormwater drainage system featuring daylighting.

24-Hour, 10-Year Event Stormwater Under Current Conditions			
Upper Reach		**Lower Reach**	
Peak Velocity, ft/s	13.3	Peak Velocity, ft/s	11.6
Peak Flow, cfs	65.2	Peak Flow, cfs	57.0
Max. Depth, ft	2.5	Max. Depth, ft	2.5

Table 3: Current 24-hour, 10-Year Stormwater Event Characteristics for Forest Theatre Project Reach

CHAPTER 2: PROBLEM IDENTIFICATION

UNC Stormwater Design Guidelines

The remainder of this report uses the standards established by the ESD to consider designs to meet the 10-yr SCS design storm while balancing the following criteria:

- Enhancing environmental protection by reducing peak discharge, reducing nutrient load, enhancing aesthetics;
- Minimizing project costs- including initial construction costs and annual operation and maintenance.

To assess the hydrology and hydraulics for this project, the Stormwater Management Model (SWMM) will be used to calculate peak runoff time, volume and flow by modeling various channel dimensions, detention sizes and routing. SWMM Version 5.1 is a computer model developed by the US Environmental Protection Agency (EPA). It is an industry standard in modeling stormwater runoff that is used in the planning, analysis and design of stormwater management systems. The University commonly uses this program in their modeling on campus.

Congress developed the Clean Water Act in 1972 which mandated the establishment of the National Pollutant Discharge Elimination System (NPDES), a permitting process that is to be implemented by each state. This permitting process requires Best Management Practices (BMP) which, in North Carolina, have been defined by the Department of Environmental Quality

NCDEQ). In this instance, BMPs are design approaches intended to limit nitrogen and phosphorus from entering the watershed to increase water quality for the area's surface water. Chapel Hill is a Phase II community; therefore, existing development must remove 85% of total suspended solids (TSS), 35% of total nitrogen (TN) and 5% of total phosphorus (TP) (Jordan Water Supply Nutrient Strategy 2007).

Design Criteria

The ESD and NCDEQ have established standards for stormwater management within the Jordan Lake watershed. The following section will describe the criteria that are followed for this project. Table 4 below shows the design criteria that this project is beholden.

Design Criteria	
Storm Event Return Period	10 years
Peak Velocity in BMPs	2 fps
Peak Velocity in Concrete Culvert	10 fps
Meet Nutrient Reduction Goals of Jordan Lake Rules	

Table 4. Design Criteria for Forest Theatre Project.

Rainfall Data

The Soil Conservation Service (SCS) Type II rainfall distribution is the design storm type designated by UNC Stormwater Management and the design standard for an open channel downstream of a Town of Chapel Hill road. The 10-year storm event will be used to design daylighting options in SWMM. The 10-year, 24-hour duration storm precipitation is 5.38 inches (UNC Stormwater Performance Criteria 2010).

Jordan Lake Rules

Jordan Lake is a focus area for state protection because it is a drinking water source for several Triangle communities and a popular recreation area (Jordan Water Supply Nutrient Strategy, 2007). Table 5 shows the current annual volume of nutrients added to Jordan Lake and the target annual goals for nutrient rates within Jordan Lake. These volumes are based on a 1997 to 2001 study by the Environmental Management Commission (Measuring Conservation Success, 2007).

Jordan Lake Nutrient Reduction Goals		
	Nitrogen	**Phosphorus**
Percent Removal	35	5
Current Annual Rate, lb	1,000,000	87,245
Target Annual Rate, lb	640,000	82,833

Table 5: Jordan Lake Nutrient Reduction Goals- Rates are based on 1997 to 2001 baseline levels (Measuring Conservation Success, 2007).

Defining the problem

This project seeks to daylight the Forest Theatre section of drainage from the UNC campus. The various stormwater management options outlined above are designed and analyzed in engineering detail in Chapter 3 to determine which option or combination of options is the most feasible to control flooding, maintain current usability of the property and gain valuable nutrient credits for a 10-year storm event. The ideal design will:

- reduce peak velocity in order to increase sedimentation to reduce nutrient-rich runoff;
- increase aesthetic appeal;
- minimize costs- initial construction costs and annual maintenance costs;
- reduce scour in the concrete culvert.

CHAPTER 3: SOLUTION IDENTIFICATION AND ANALYSIS

Introduction

Chapter 3 identifies the BMPs that have acceptable criteria for the project goals and the four design options for daylighting the Forest Theatre stormwater drainage system:

- Option One: Daylighting by an irregular shaped channel lined with multicolored, smooth stone (stonework) and vegetation;
- Option Two: Daylighting with a Wet Detention Basin
- Option Three: Daylighting with two Wet Detention Basins and
- Option Four: No action alternative, i.e. the existing system.

Best Management Practices for Stormwater Drainage to Protect the Environment

There are a variety of BMPs that are recognized as effective stormwater mitigating practices by NCDEQ but they were not suitable for this project area due to safety factors, foot traffic and space limitations. Grassed swales, wet detention basins and dry detention basins were found to be best suited for this project and will be discussed further in this section.

Grassed Swales

Grassed swales are shallow channels with mild longitudinal slopes (1 to 2.5%,) and flow depths below the height of the vegetation that grows within them or rocks that line them (Water Environment Federation, p268)**.** They remove pollutants from stormwater by biofiltration, settling, and infiltration. Grassed swales filter pollutants as stormwater runoff moves through the leaves and roots of the grass. By reducing flow velocities and increasing a site's time of concentration, grassed swales contribute to reducing runoff peaks. Grassed swales that are designed with check dams or incorporate depression storage promote infiltration and can help contribute to satisfying a site runoff capture/storage requirement (SW Management BMP 2007).

The effectiveness of a swale in both (1) reducing the flow rates and volume of runoff and (2) removing pollutants, is a function of the size and composition of the drainage area, the slope and cross section of the channel, the permeability of the soil, the density and type of vegetation in the swales, and the swale dimensions. Broad swales on flat slopes with dense vegetation are the most effective; however, because of the local topography, this project will not have a flat slope. Removal efficiencies are highest for sediment-bound pollutants (SW Management BMP 2007).

The design parameters for the grassed swales are: the maximum velocity must be 1 ft/ sec. for the 10-year storm; the side slopes will not be steeper than 5:1; and the swale length must be 150 ft. or greater (SW Management BMP 2007), (UNC Stormwater Performance Criteria 2010).

For this BMP, the grassed swales would be the daylighted section of the current pipe. While the slopes of the project area fall within the allowable longitudinal slope range, the width of the grassed swale far exceeded the area that is available. In order to function properly, the minimum dimensions for a grassed swale on the upper reach would have to be:

- Bottom width: 150 ft;
- Side slopes: 5ft to 1 ft;
- Maximum depth: 5 ft;
- Manning's value: 0.05;

The maximum width in the upper reach is approximately 100 ft. Therefore, grassed swales are excluded as a viable technical alternative.

Wet Detention Basin

In wet detention basins, a permanent pool of standing water is maintained by a weir. Water in the permanent pool mixes with and dilutes the initial runoff from storm events. Wet detention basins are designed to fill with stormwater and release most of the mixed flow over an extended period (through a weir, orifice, or other flow regulator), thus slowly returning the basin to its normal depth (SW Management BMP 2007).

Runoff generated during the early phases of a storm usually has the highest concentrations of sediment and dissolved pollutants. Because a wet detention basin dilutes and settles pollutants in the initial runoff, the concentration of pollutants in the runoff released downstream is reduced. Two mechanisms that remove pollutants in wet detention basins include settling of suspended particulates and biological uptake, or consumption of pollutants by plants, algae, and bacteria in the water. A drawback of this design is also continued maintenance because if the basin is not adequately maintained (periodic excavation of the captured sediment), storm flows may create turbidity in the basin and return the sediment to the stream (SW Management BMP 2007).

Dry Detention Basin

These basins are usually dry between storm events. An outlet slowly releases water retained over a period of days. The primary purpose of dry extended detention basins is to attenuate and delay stormwater runoff peaks. They are implemented where water quality issues are secondary to managing peak runoff, since the overall pollutant removal efficiency of dry extended detention basins is low. Dry detention basins are not intended as infiltration or groundwater recharge measures (SW Management BMP 2007).

	Peak Attenuation	TSS Removal Efficiency	TN Removal Efficiency	TP Removal Efficiency
Grassed Swales	Yes	0-35%	0-20%	0-20%
Wet Detention Basin	Yes	85%	25%	40%
Dry Detention Basin	Yes	50%	10%	10%

Table 6: BMP Ability for Stormwater Quality Control, Source: SW Management BMP 2007.

The methods for analysis of each design are described in detail then the designs are analyzed using EPA-SWMM. Nutrient reduction amounts are then estimated using the Chesapeake Bay Program approved removal rates- this method of analysis is not thought to be accurate for this daylighting project but is a rough guideline on which to study this project. Proposed vegetation options are discussed and the optimal design is then selected.

Design Options One, Two and Three all include 104’of rectangular box culvert at the downstream end. This culvert is made up of 13 sections of 8’ long precast reinforced concrete box culvert.

Design Option One: Simple Daylighting

This design is the most basic and low maintenance of the three proposed designs that will alter the current stormwater drainage system. It consists of two sections of irregular shaped channel design. The divide in the section occurs where a third line enters the section at approximately 200 feet delivering a larger load to the lower reach. The irregular shape was designed using current topography of the area and to allow for the 24-hour, 10-year storm event to dissipate over a floodplain. These three designs were found to be better than a simple trapezoidal shaped channel because they transports the smaller storms, (one-, two- and five-year storm events,) in the main channel and also carry the 10-year storm events in the floodplain sections. The floodplains allow for maximum accessibility to the project area without requiring a deeper channel. Table 5 details the length, material, Manning’s n value and slope of the reach while Figure 3 shows the configuration. The channel is lined with a multicolored, rounded stone stonework which will allow seepage- but it was not modelled making these designs more conservative- and will include native flora that are described in the ‘Proposed Vegetation’ section.

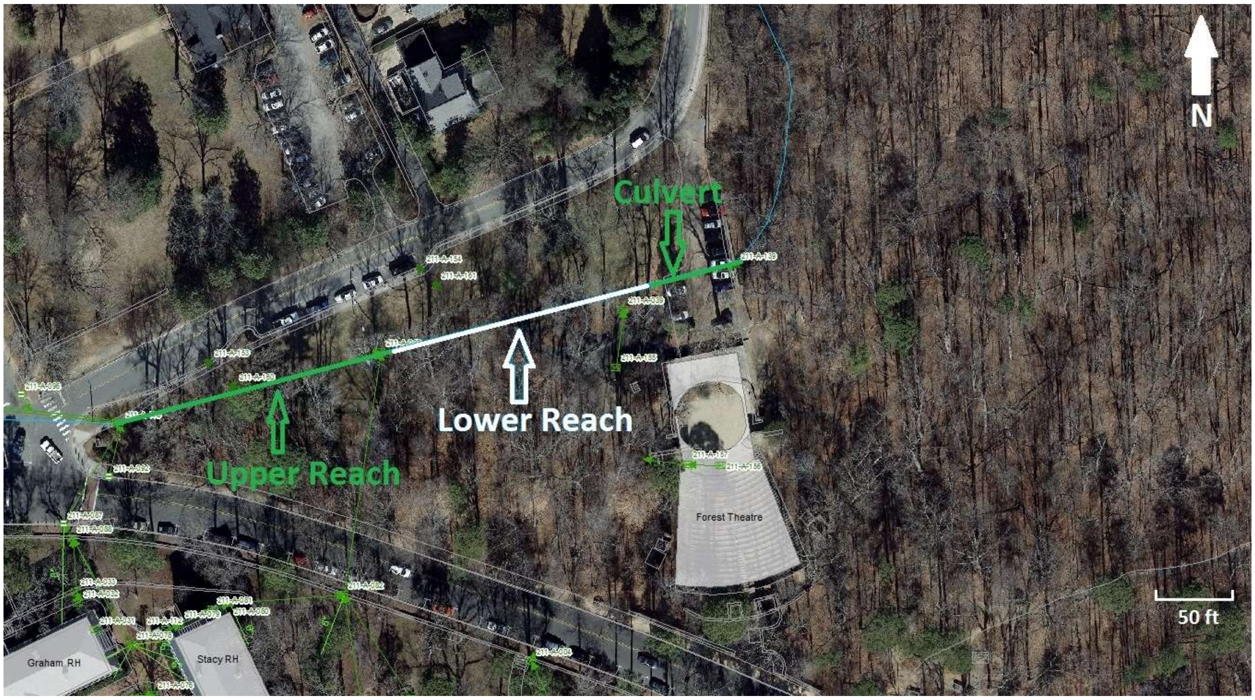

Figure 3: Schematic of Design Option One

Conduit	Length, ft	Volume, yd^3	Roughness, n	Shape	Slope
Upper Reach	194	1,024	0.05	Irregular	2.5%
Lower Reach	160	1,891	0.05	Irregular	2.6%
Culvert	104	31	0.013	4’X3’ Closed Rectangular Culvert	1%

Table 7: Design Option One Section Details

EPA-SWMM uses the existing topography of an area to determine a ‘best-fit’ profile for altering a landscape. Each design option- One, Two and Three- minimizes the alteration of the existing landscape to create a channel that will transport a 10-year rainfall event. The proposed cross-section of each reach is shown below in Figures 4 and 5:

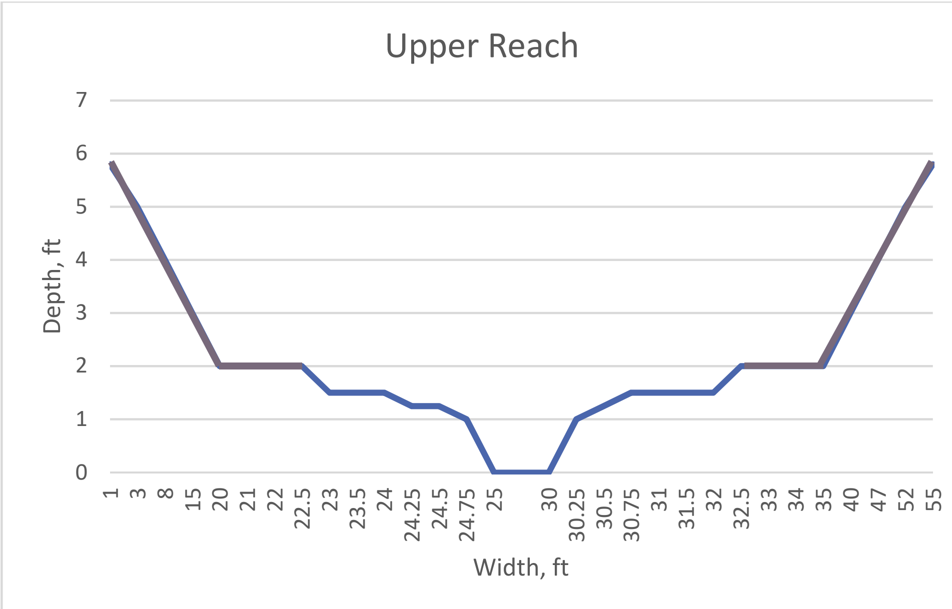

Figure 4: Design Option One Upper Cross-sectional Diagram.

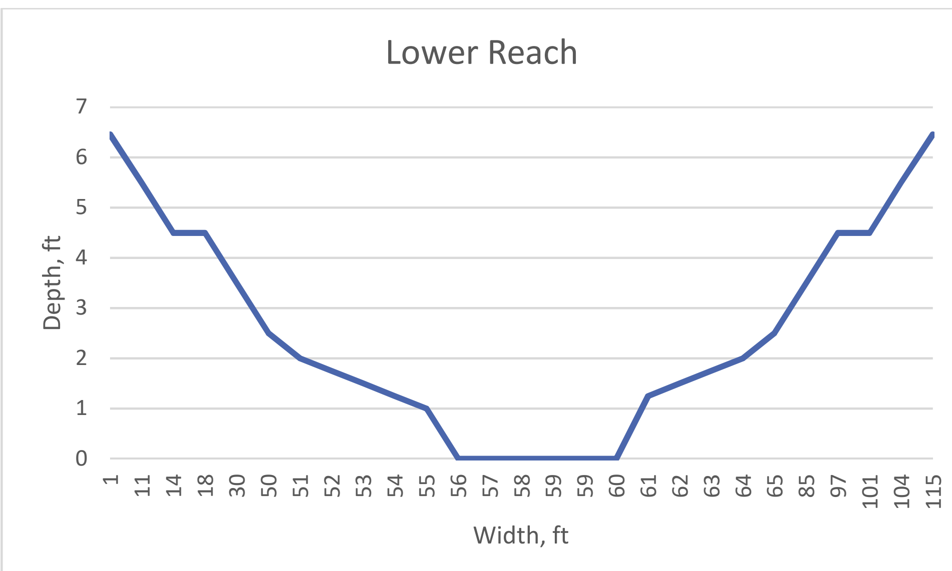

Figure 5: Design Option One Lower Cross-sectional Diagram

Design Option Two: Daylighting with Storage

This design is narrower than Design Option One and includes a 7800 ft^3 storage unit. This design that can be seen in Figure 6. This option was sized to minimize land use but still transport the runoff from the 24-hour, 10-year storm event without overtopping. Channel material types proposed in this option are the same as in the previous option, multicolored stonework. As can be seen in Figure 6 below, stormwater enters into the project area at ‘Upper A,’ flows into ‘Upper B’ which then empties into ‘Storage 1.’ From ‘Storage 1’ the stormwater flows to ‘Lower’ through the box culvert and out of the system. Conduit ‘Upper A’ is similar in shape and length to ‘Upper Reach’ in Option One. Figure 7 shows the cross-sectional diagram of conduit ‘Upper A.’ Conduit ‘Upper B’ is a short reach that simulates a shallow ripple before entering ‘Storage 1;’ the cross section can be seen in Figure 8. This reach acts as an inlet box that makes annual maintenance easier by having a shallow area that can be cleaned out with excavation equipment. Table 8 shows the design details of each section.

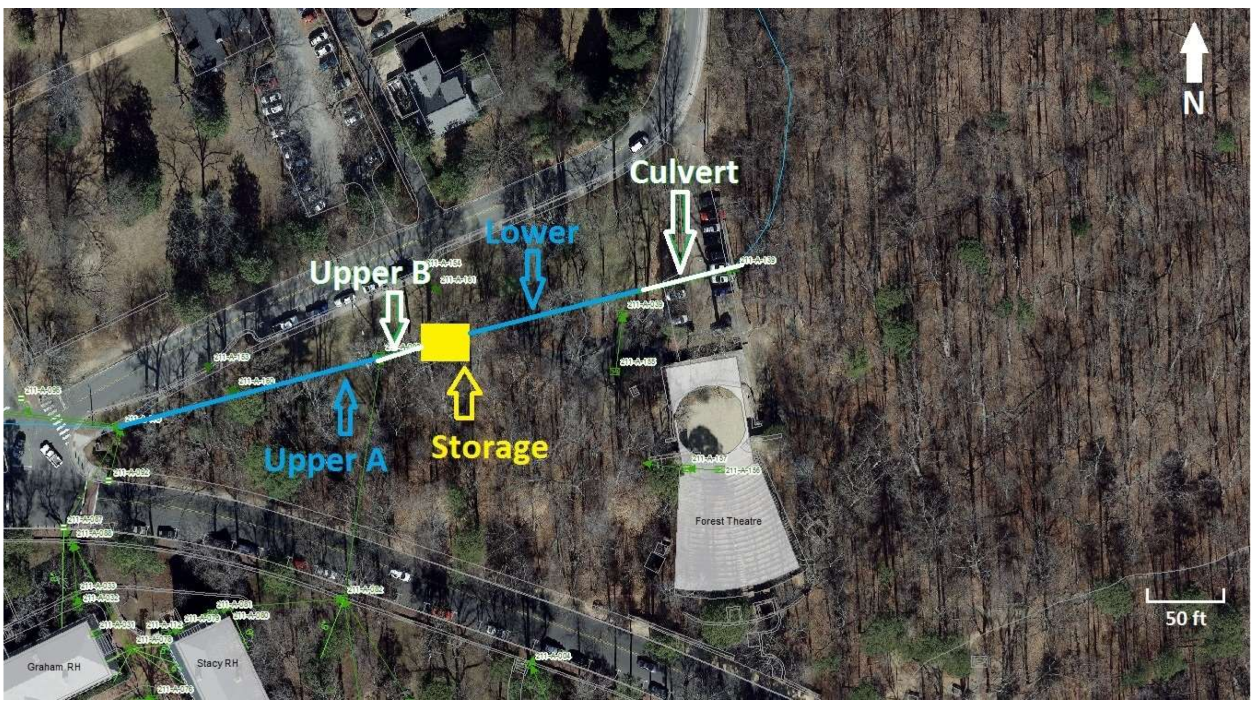

Figure 6: Schematic of Design Option Two Conduit and Storage Unit

The purpose of the storage unit is peak flow attenuation and sediment removal. Reducing the velocity allows for sediment to settle before the runoff is discharged out of the project area and increased sedimentation. The storage unit permits narrower channels than ‘Design Option 1’ (which does not have a storage unit) that maintain the current user accessibility and allows Forest Theatre visitors space to access the theatre. Since the purpose of the storage unit is sedimentation accumulation, the bottom of the unit will be lined in concrete to allow for cleaning out of the unit and the banks will be stonework. The storage is "inline", so stormwater flows directly from conduit 'Upper B' to the storage unit, where they are impounded temporarily by a v-notch weir then released through this weir directly downstream into the lower reaches. Offline storage was considered with the thought that it would function more efficiently, but the limited space of the project area does not allow such construction. An inline storage unit with concrete-lined bottom and stonework banks will be designed for both options two and three.

Conduit	Length, ft	Volume, yd^3	Roughness, n	Shape	Slope
Upper A	179	737	0.05	Irregular	1.6%
Upper B	10	40	0.05	Irregular	20%
Storage	25	290	0.05	Trapezoidal	-
Lower	140	1,157	0.05	Irregular	6%
Culvert	104	31	0.013	4'X3' Closed Rectangular Culvert	1%

Table 8: Design Option Two Section Details

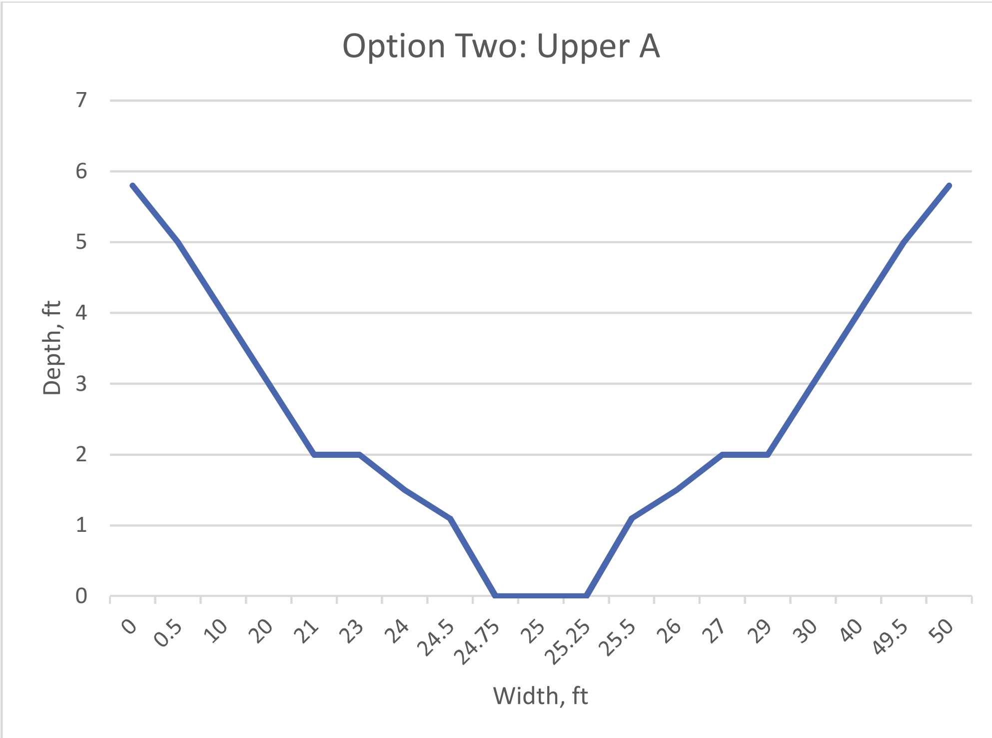

Figure 7: Design Option Two Cross-sectional Diagram Above Storage Unit

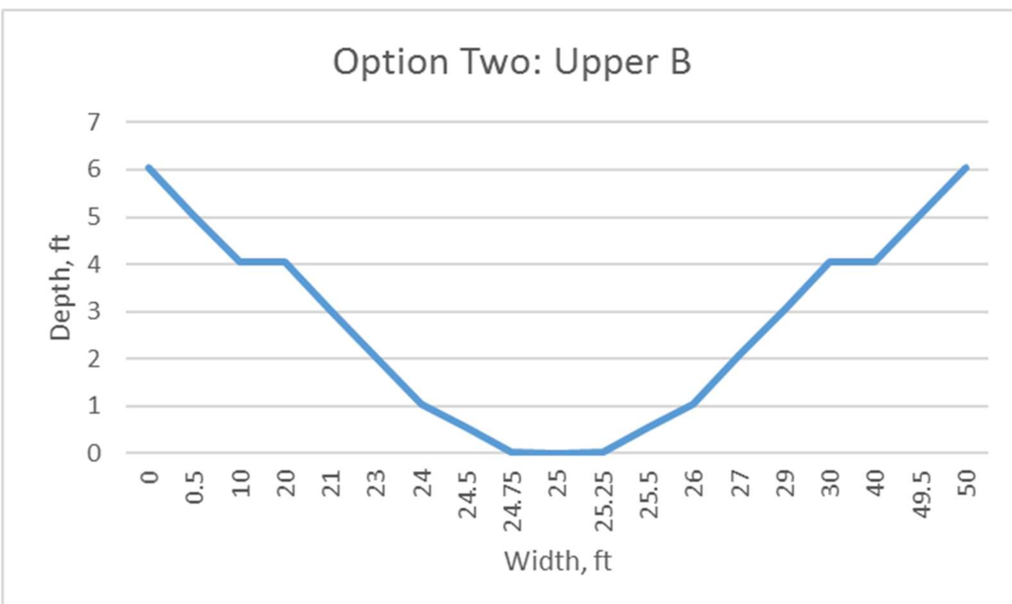

Figure 8: Design Option Two Cross-sectional Diagram Above Storage Unit

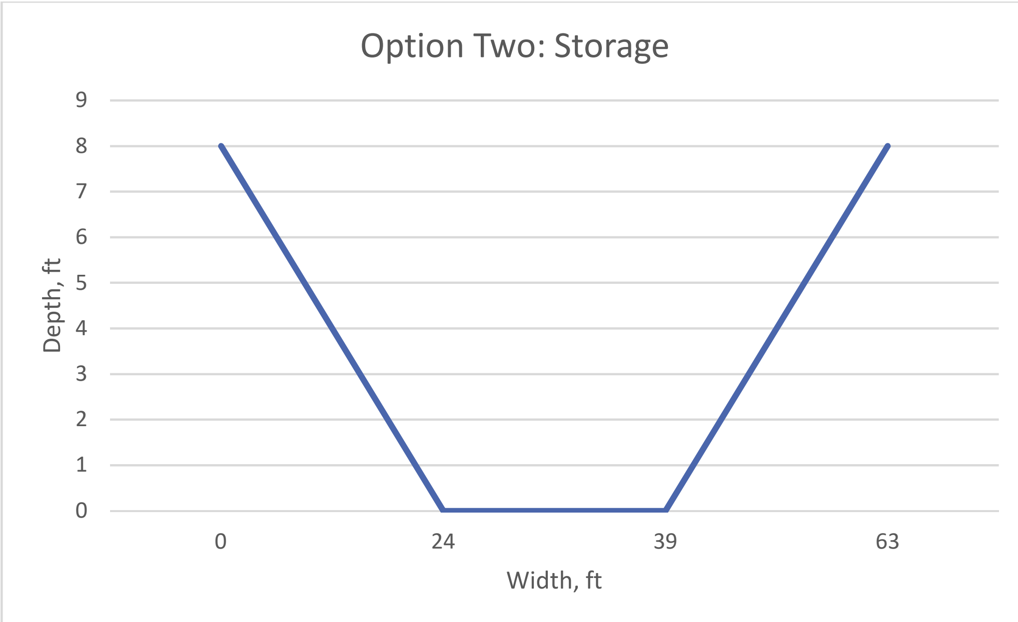

Figure 9: Design Option Two Storage Unit

The storage unit has a v-notch weir on the downstream outlet that was sized to impede runoff in the storage unit to reduce velocity and allow for additional sedimentation. The weir was sized to slow the flow through the lower section of the design. The material will be concrete with an ornamental rock façade to match the surrounding multicolored stonework. The characteristics are:

Shape	Side Slopes, (H/V)	Height, ft	Length, ft	Discharge Coeff.
V-Notch	5:1	4	10	3

Table 9: Weir Characteristics for Design Option Two Storage

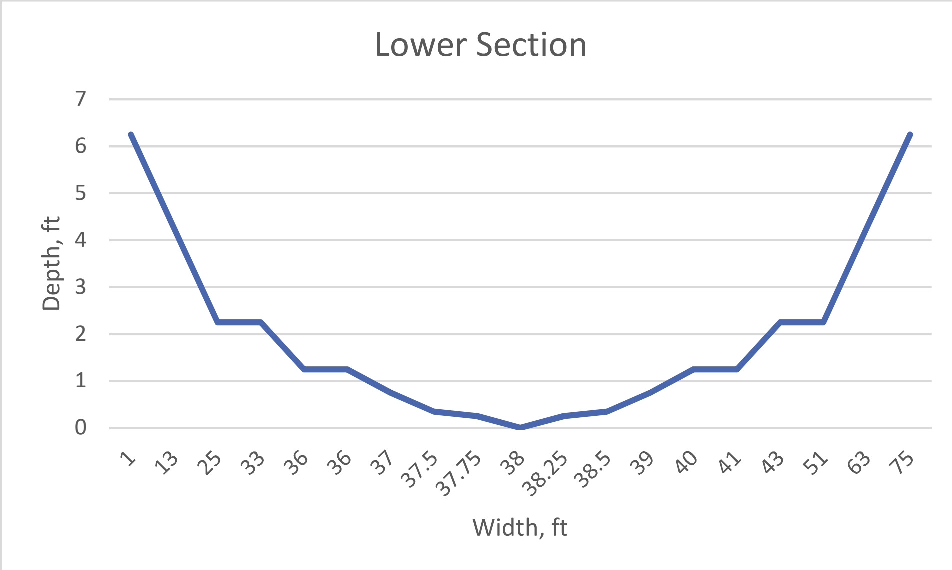

Figure 10: Design Option Two Cross-sectional Diagram Below Storage Unit

Design Option Three: Daylighting with Two Storage Units

This design is the most conservative of the three design options with two large storage areas.

As can be seen from Figures 12 and 13, the channel of the upper reach is similar to the Design Option Two before entering 'Storage 1', with approximately 21,000ft^3 of storage spanning 189 linear feet with a storage unit of 7800ft^3. Stormwater enters the design area at conduit 'Upper A,' flows into 'Upper B' before entering 'Storage One.' The stormwater is then discharged through a weir to 'Lower A' and then into 'Lower B' before being impounded in "Storage Two' and flowing out of the project area. This can be seen in Figure 11.

Conduit 'Upper B' functions as a shallow section that provides a rippling effect before the water enters 'Storage 1.' Figure 11 shows the layout of each conduit and the inline storage areas. Table 10 shows the details of each reach- length, volume of storage, Manning's n, shape and slope.

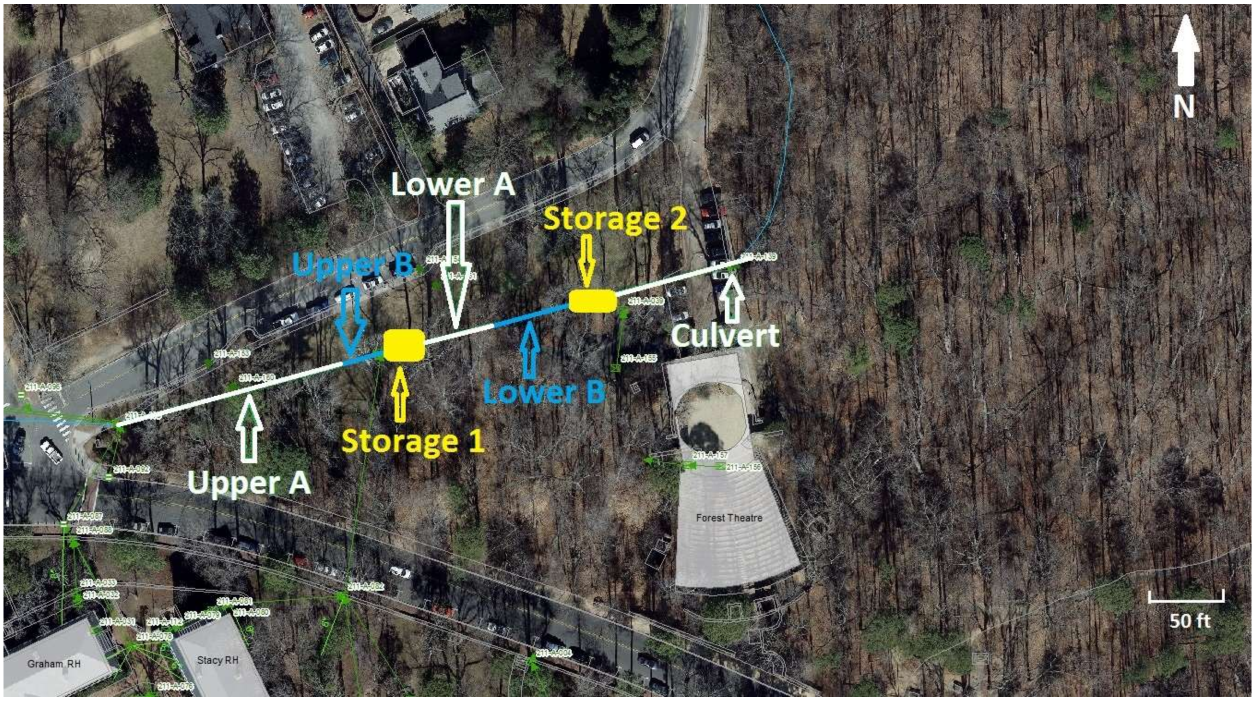

Figure 11: Schematic of Design Option Three Conduit and Storage Units

Conduit	Length, ft	Volume, yd^3	Roughness, n	Shape	Slope
Upper A	179	737	0.05	Irregular	1.6%
Upper B	10	40	0.05	Irregular	17%
Storage	25	290	0.05	Trapezoidal	-
Lower A	55	350	0.05	Irregular	4%
Lower B	55	104	0.05	Irregular	4%
Storage 2	30	520	0.05	Irregular	-
Culvert	104	31	0.013	4’X2’ Closed Rectangular Culvert	1%

Table 10: Design Option Three Section Details

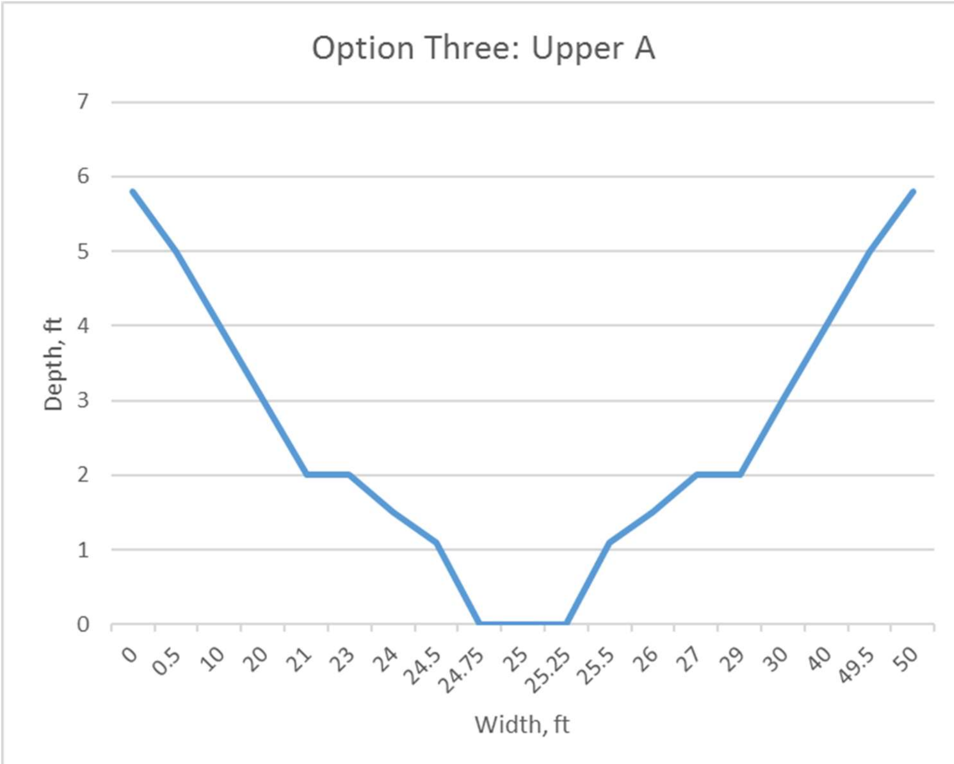

Figure 12: Design Option Three Cross-sectional Diagram Above Storage Unit

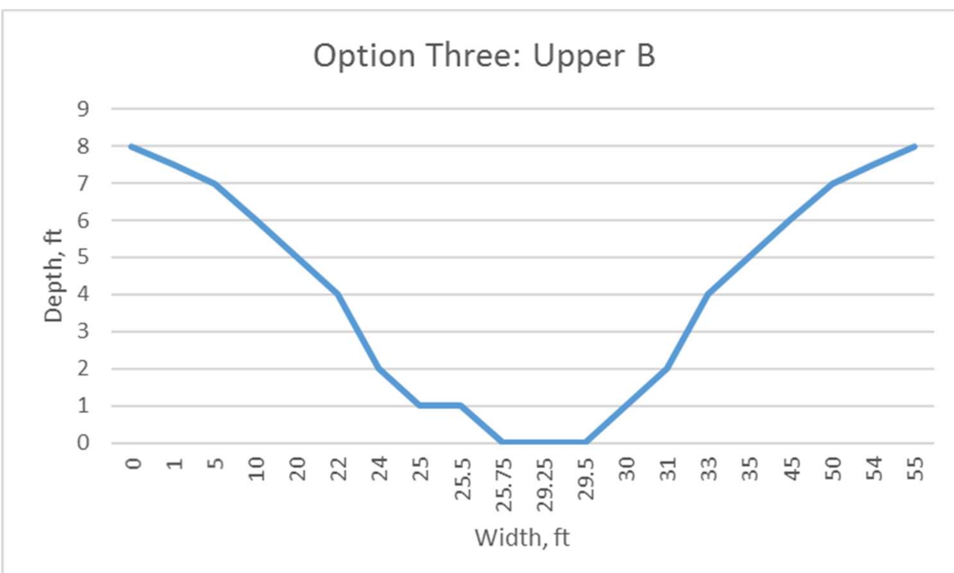

Figure 13: Design Option Three Cross-sectional Diagram Above Storage Unit

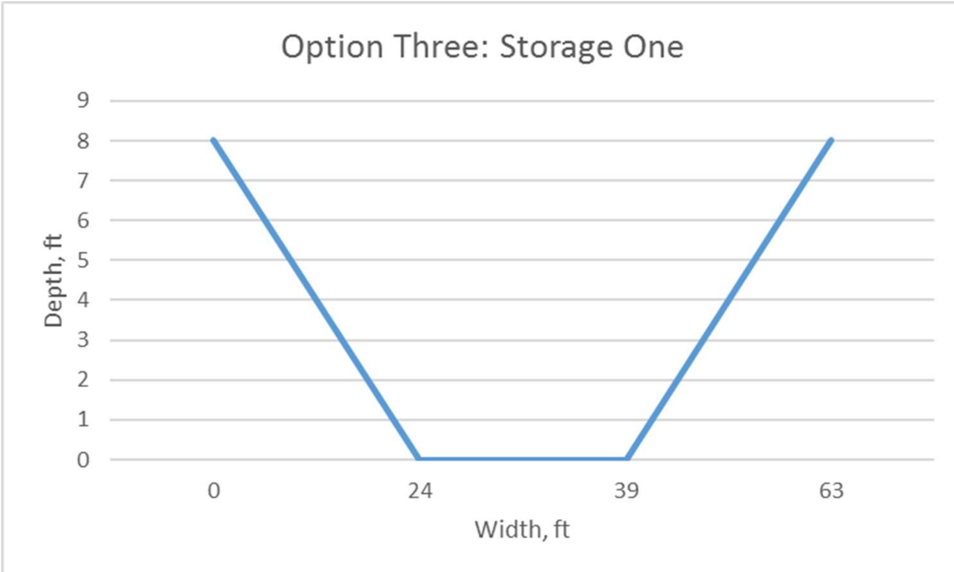

Figure 14: Design Option Three Storage One

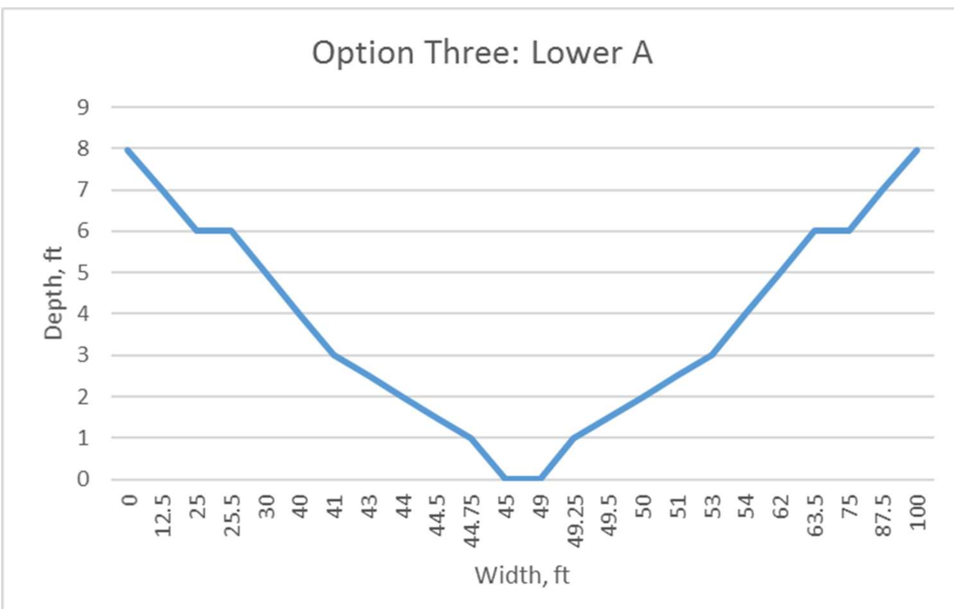

Figure 15: Design Option Three Cross-sectional Diagram Below Storage Unit

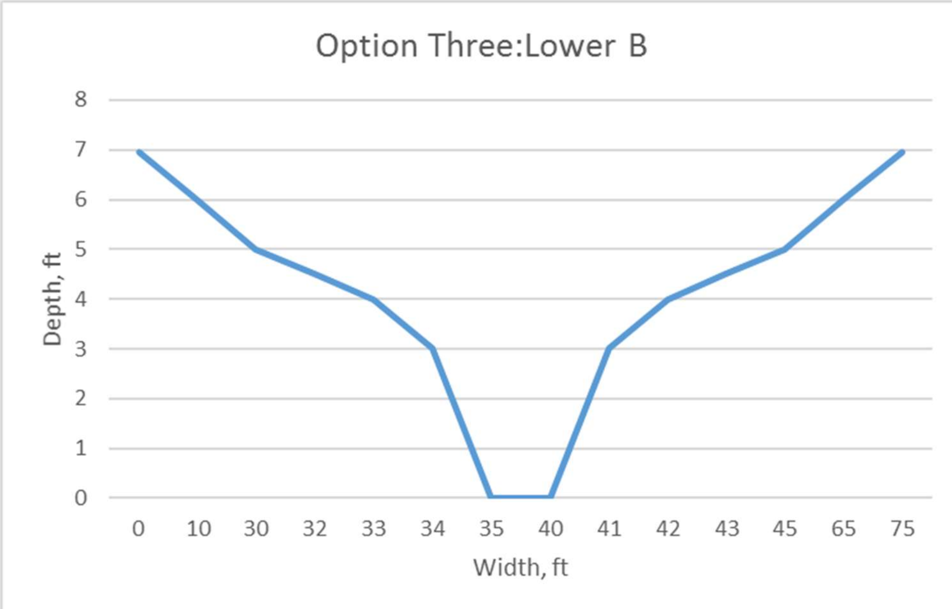

Figure 16: Design Option Three Cross-sectional Diagram Below Storage Unit

As can be seen in Figure 17, 'Storage Two' provides a large floodplain for the designed storm event with a width of 200 feet. For the 10-year storm event, the main channel is depicted in blue while the floodplain, 180 ft, is depicted by the thicker brown line. This reduces the stormwater to reduce velocity by distributing the discharge over a larger area before entering the closed rectangular conduit. The 'Storage 2' outlet will function as an orifice during high runoff events as the culvert entrance will be submerged and pressurized for approximately two hours during the 24-hour, 10-year event. The design specifications for each storage units' weir can be seen in Table 11 below.

Figure 17: Design Option Three Cross-section design, Storage Unit 2

	Outlet Type	Shape	Width, ft	Height, ft	Discharge Coeff.
Storage 1	Weir	Trapezoidal	10	5	3 [1]
Storage 2	Orifice	Rectangular	4	2	0.35 [2]

Table 11: Weirs Specifications for 'Design Option Three'

Proposed Vegetation

Vegetation will be planted along the daylighted sections to increase aesthetic appeal. The trees, shrubs, herbs and graminoids will be native to the Piedmont area and will provide good ground

[1] The Francis formula is used to determine flow across a sharp-crested weir when neglecting approach velocity:

$$Q = C * (b - 0.2H) * H^{3/2}$$

Where,

Q = flow, cfs
C = discharge coefficient
b = width of weir, ft
H = head above weir, ft

[2] The orifice equation is used for determining flow here:

$$Q = \frac{\pi}{4} C d^2 \sqrt{2gh}$$

Where,

Q = flow, cfs
C = discharge coefficient
d = orifice diameter, ft
g = gravitational acceleration,
h = depth of flow, ft

cover and act as a safety barrier to the riparian area ("Recommended Native Plant Species for Stream Restoration in the Piedmont, North Carolina"). Recommendations from the UNC Botanical Garden can be found in Table 20 in Appendix B.

Parking Spaces

Parking spaces in Parking Lot N5 will only be reduced during construction and no spaces will be permanently lost due to the project. The project was designed to avoid reducing any spaces for a long duration due to the high cost of each space; approximately $20,000 for each space that is lost (UNC Parking – Parking and Transportation, 2016).

Methods for Analysis

Hydraulic and hydrologic models were analyzed using EPA-SWMM, the United States Environmental Protection Agency's (US EPA) Storm Water Management Model (SWMM), which is a widely-used industry standard. EPA-SWMM calculates flow characteristics with the Green-Ampt infiltration method and dynamic wave routing. The dynamic wave routine involves formulating solutions for the gradually-varied, unsteady flow equations, also known as the Saint-Venant equations. The unsteady flow continuity equation and the momentum equation are combined and solved along each conduit for each time step. Numerical integration of the two equations is achieved by the Modified Euler Method, allowing for the formulation of solutions that satisfy both equations simultaneously (James, W.; Rossman, L; and James, W. R.; 2010).

Calculation of overland flow routing begins with determining the typical amount of depression storage depending on subcatchment cover type, imperviousness, and slope. During the simulation, once available depression storage has been filled, overland flow is calculated by simultaneously solving the continuity equation and Manning equations, using catchment shape, slope, and roughness as input parameters. Subcatchment time of concentration is then calculated using the kinematic wave formulation and used in the peak flow analysis (James, W.; Rossman, L; and James, W. R.; 2010). Relevant tables and figures describing Intensity, Duration, Frequency curves can be found in Appendix A. The Manning equation is used for open channel flow while the Hazen-Williams equation is used for pressured flow analysis.

Stormwater models were adapted for the purposes of this report from a model produced by RK&K Consulting Engineers on a contractual basis with UNC Chapel Hill (RK&K, 2013) as described in Chapter 1. Infiltration parameters such as hydraulic conductivity, suction head, and porosity correspond to the soil type characteristics of each respective subcatchment; however, these parameters are not likely to have a significant effect on the overall model unless a timeframe greater than 24 hours are analyzed. Percent slope was calculated using topographical contour lines and a rudimentary topographical assessment using the level and grade rod technique, while subcatchment imperviousness parameters were estimated on a GIS layer depicting UNC Chapel Hill land use and reviewing the UNC Campus Master Plan (March 2006). Finally, Manning's n values for the drainage channel were assumed to be 0.05 based on the American Society of Civil Engineers (ASCE) Manual of Practice (1982), see Table 10 below, also cited by the SWMM User's Manual (2010). Channel sections are rock bottomed with stone or vegetated banks.

Sensitivity analyses were conducted for all Manning's n values, including channel flow and overland flow for pervious and impervious surfaces. Values of Manning's n were varied between 0.02 and 0.10 but had the least effect of any variables upon peak flow rates, altering them by less than 1% for analysis (SWMM). Table 12 details the Manning's n that were used for the sensitivity analysis. It was found that variations in channel design and storage units had the greatest impact on velocity and flow and were therefore adjusted for each design option. The three major variables that were adjusted for channel design were width of reach, depth of reach and slope of reach.

Channel Type	Manning n
Excavated or dredged	
-Earth, straight and uniform	0.020 – 0.030
-Earth, winding, fairly uniform	0.025 – 0.040
-Rock	0.030 – 0.045
-Unmaintained	0.050 – 0.045
Natural channels (minor streams, top width at flood stage < 100 ft)	
-Fairly regular section	0.030 – 0.070
-Irregular section with pools	0.040 – 0.100

Table 12: Manning's n Values for Various Channel Types

Nutrient Removal Rates for Best Management Practices

Earning nutrient credits is a driver for this daylighting project in order to maintain compliance with the Jordan Lake Rules that were detailed in Chapter 1. Through the guidance of the ESD, the Chesapeake Bay Program was adopted as a model for nutrient reduction values for qualifying stream restoration. While conditions are different between the two regions the Chesapeake data appear to be the best available source of information. The Chesapeake Bay Program is a regional partnership- New York, Pennsylvania, West Virginia and Virginia- that directs and conducts the restoration of the Chesapeake Bay in the United States. The program signed an agreement in 1987 to reduce nutrients in the Bay through restoration projects in the watershed, a program that is similar to the Jordan Lake Rules that govern this project.

In retrospect, this data is a doubtful baseline for estimating the total amount of nutrients and total suspended solids removed from the site because this project is not a stream restoration where cut banks and high erosion are found. This study was nevertheless the closest representation that could be found as an estimate for nutrient removal. A single monitoring study from Baltimore Co, Maryland, will be used to estimate nutrient removal rates for this daylighting project. The data for urban stream nutrient removal was collected in a medium density residential developed sub-watershed with an area of 481 acres. Original monitoring occurred for two years before the project was implemented and three years after project completion. A total of 10,000 linear feet of stream was restored. The results from this study can be seen in Table 13 below (Berg, Burch et al. 2013). While this study is very different from the Forest Theatre Daylighting Project, it was used to provide one estimate of the amount of nutrients removed by this project. These default rates were established when projects are not able to monitor performance directly ("Urban Stream Restoration Fact Sheet, 2015). While this project aims to reduce TN, TP and sedimentation, at this time, there will be no monitoring to determine exact rates before the project; however, the ESD could decide to monitor in the future. It should be noted that much of the nutrient benefits from the Baltimore Co. stream restoration project are attributable to minimized streambank sloughing, which in turn reduced the amount of sedimentation coming from bank erosion; this mechanism has no bearing on this daylighting project.

Approved Removal Rates per Linear Foot of Qualifying Stream Restoration				
	TN	TP	TSS	
Removal Rate	0.02	0.0035	2.55	lb/ft/yr

Table 11: Stream Restoration Nutrient Removal Rates. (Burg, Berch, et al. 2013).

Explanation of Evaluation Criteria

Options were compared by assessing performance against six criteria. These criteria were:

- Peak velocity/ flow reduction
- Nutrient Removal
- Aesthetic Enhancement
- Cost/ Ease of Maintenance
- Construction Costs
- Concrete Culvert Scour

The peak stormwater velocity reduction criterion describes how effective the option is at reducing stormwater runoff velocity from the site. When velocities are below 2 fps, best management practices function optimally by removing nutrients through sedimentation, peak flow attenuation through storage in the system and erosion control downstream. For this criterion the ranking high means the option has the highest reduction of velocity during a 24-hour event, medium means it reduces some of the stormwater runoff velocity during a 24-hour event and low means there is little or no reduction of stormwater runoff velocity during a 24-hour event.

The next criterion is whether the option removes nutrients from the stormwater. For this criterion the ranking high means the project has design mechanisms in place that reduce nutrients in stormwater runoff and a ranking of low means the project has no mechanism for nutrient removal.

The cost criterion ranks the construction cost of implementing the design option. A high ranking means that a project is of low cost and can be done in house with ESD staff and construction crews. A medium ranking means the project falls under the University's informal bidding process and will use contractors that are on call with a total cost of less than $500,000. A low ranking is a project that is estimated to cost more than $500,000 and requires a formal bidding process. The ranking categories for this criterion are based on ESD staff suggestions.

The ease of operation and maintenance criterion ranks the amount of maintenance, training and operational procedures required for the option. A high ranking means there is little maintenance required and no training or operation procedures, a medium ranking means there is some maintenance required and no training or operation procedures and a low ranking means there is frequent maintenance required and/or training and operation procedures.

The aesthetic appeal criterion describes the impact to the local environment caused by the project. A high ranking means that there is a significant positive aesthetic impact on the local environment, a medium ranking means there is some positive aesthetic impact on the local environment and a low ranking means there is a significant negative aesthetic impact on local environment. It is acknowledged that aesthetic appeal is a subjective criterion but one that still needs to be assessed.

The last criterion is scour occurring in the concrete culvert sections under the parking lot. Scour is caused by high velocity (greater than 10 fps) through the culvert. Minimizing velocity at the discharge also reduces erosion downstream by decreasing cut-banks. A high ranking is awarded when peak velocity is less than 10fps, a medium ranking means peak velocity is 10 to 15 feet per second and a low ranking means peak velocity is greater than 15fps.

Analysis

Velocities and Flows

All of the design models were simulated as a 24-hour, 10-year storm event and the results from EPA-SWMM are shown in the following section. The velocity should be low, less than 2 fps, for a

BMP to function properly. The lower velocity allows greater time for sedimentation to occur thus reducing TN and TP levels; however, these sediments can accumulate reducing storage volume over time which will increase maintenance costs. This is a balancing act.

The following table details the peak velocity of each conduit then ranks the design option on total time with velocity greater than 2 feet per second (fps) and scour in the culverts. Two fps is chosen because that is the highest velocity for a BMP to function properly, allowing for sedimentation, peak flow attenuation through storage in the system and reduced erosion downstream.

24-Hour, 10-Year Storm Peak Velocities			
	Conduit	Peak Velocity, fps	Rank
Option 1	Upper	3.3	
	Lower	3.66	
	Culvert	**13.69**	2
Option 2	Upper A	2.53	
	Lower	5.69	
	Culvert	**9.91**	1
Option 3	Upper A	3.20	
	Upper B	7.89	
	Lower A	3.92	
	Lower B	3.55	
	Culvert	**13.48**	3

Table 14: Velocity for Each Conduit during 24-hr, 10-Year Storm

The culverts are marked in bold in Table 14 flow under the parking lot. Higher velocities in these sections are ideal to remove the stormwater from the area to minimize flooding during storms larger than the 10-year event but velocities higher than 10fps can cause scouring of the concrete due to debris in the runoff. It should also be noted that the higher velocities occur in conduit that are narrower or have a higher slope over a short span. Option Two is ranked the highest due to the fact that it maintains a velocity of less than 10fps in the culvert. A variety of conduit dimensions were analyzed with minimal effect on peak velocity.

The figures below were taken from EPA-SWMM at the peak height of flow through the project area for the three modeled options. The energy grade line (EGL) can be seen as the thin blue line and the water level is represented by the light blue and dark blue meeting point. Junctions, where the conduit shape changes, are represented by the vertical rectangle. A system failure occurs when the waterline reaches the top of the junction.

In Figure 18 below, it can be noted that there is no failure throughout 'Design Option 1' representing a satisfactory design to handle the 24-hour, 10-year storm event. This design has a 6.5' headwall located at junction J4 to separate the daylighted stream from the parking lot that is located above the closed rectangular culvert.

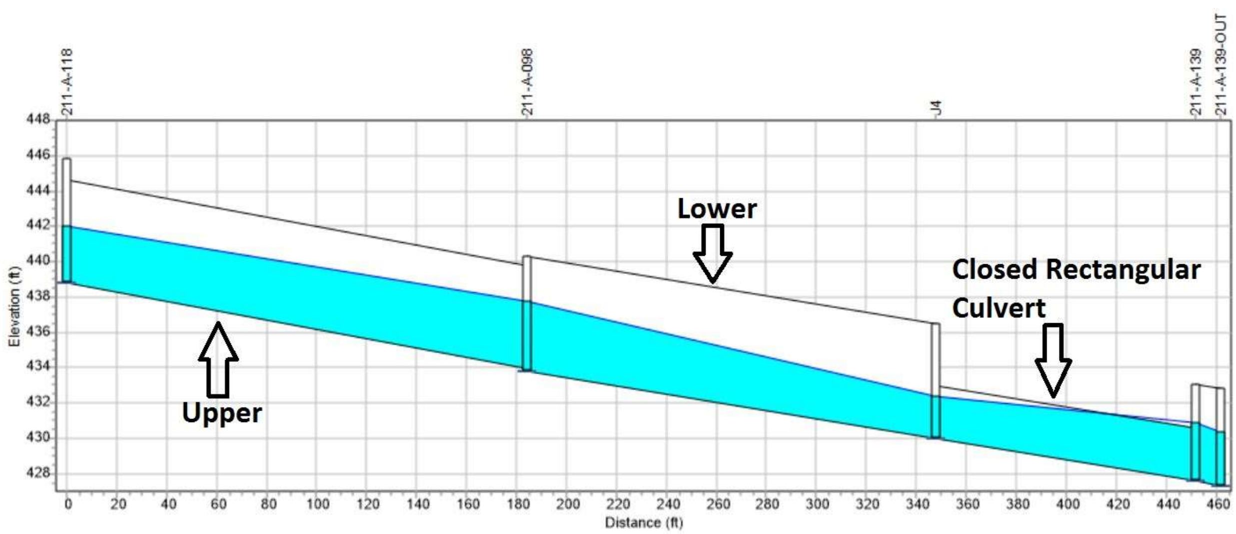

Figure 18: Design Option One Peak Water Elevation Profile for Project Area during 24-Hour, 10-Year Storm.

Figure 19 shows ‘Design Option 2.’ It can be noted that due to the storage unit, stormwater runoff is backed up to increase depth upstream of the storage unit. This results in increased sedimentation due to decrease velocity. The bolded brown line shows where sedimentation will build throughout storm events and will need to be cleared approximately every five years (Hoyt, 2016). A headwall is located directly upstream of the closed rectangular culvert that is 6.5 ft high. Figure 19 shows that this design will not fail in a 24-hour, 10-year storm event.

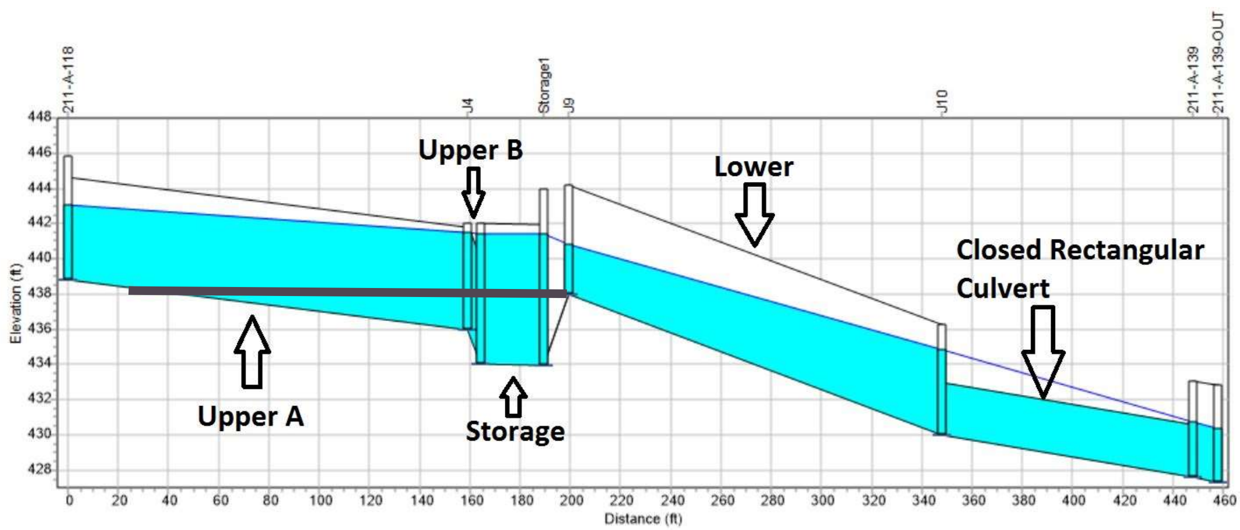

Figure 19: Design Option Two Peak Water Profile Elevation for Project Area during 24-Hour, 10-Year Event.

Figure 20 below shows the functionality of Storage Unit One in the flows above and below the storage unit. As can be seen in the representation of the ‘Upper A’ reach, flow is approximately 130cfs and at the effluent of the storage unit the flow decreases to approximately 110cfs showing that the storage unit decreases the flow by 15%, not a significant amount alone. This shows that the storage unit is more effective as a sediment collector.

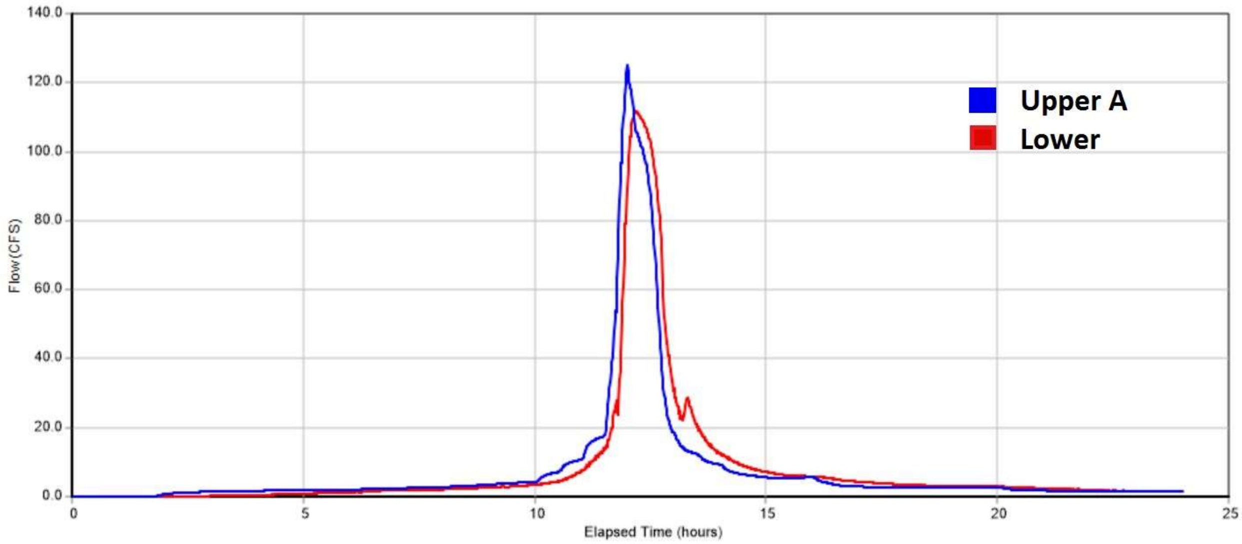

Figure 20: Hydrograph representing flow effect of Storage Unit One.

The 24-hour, 10-year storm is shown below in Figure 21 for 'Design Option Three.' Storage 2 may introduce hydraulic storage where water is delayed but there will not be a significant amount of sedimentation accumulation as can be seen in Figure 21 due to the fact of the matching inverts of Storage 2 and the culvert. It is thought that the sediment will travel through this storage area, not contributing to nutrient removal. 'Storage 1' has a bolded line that shows where sedimentation will build and have to be maintained approximately every 5 years (Hoyt. 2016).

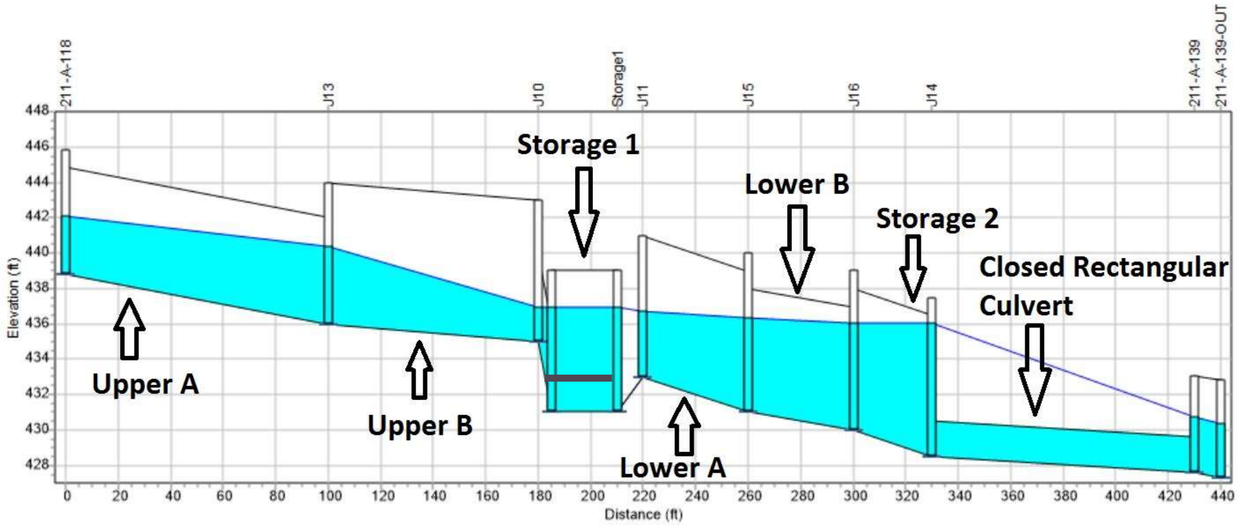

Figure 21: Design Option Three Peak Water Profile Elevation for Project Area during 24-Hour, 10-Year Event.

Figure 22 shows the functionality of storage unit one, 7830ft^3 reducing flow between the upstream and downstream reaches. Flow is reduced by the storage unit by approximately 9% making this an important feature of this daylighting project while also making an aesthetic contribution. This impact of this storage unit is not considered to be significant and would not be worthwhile to maintain.

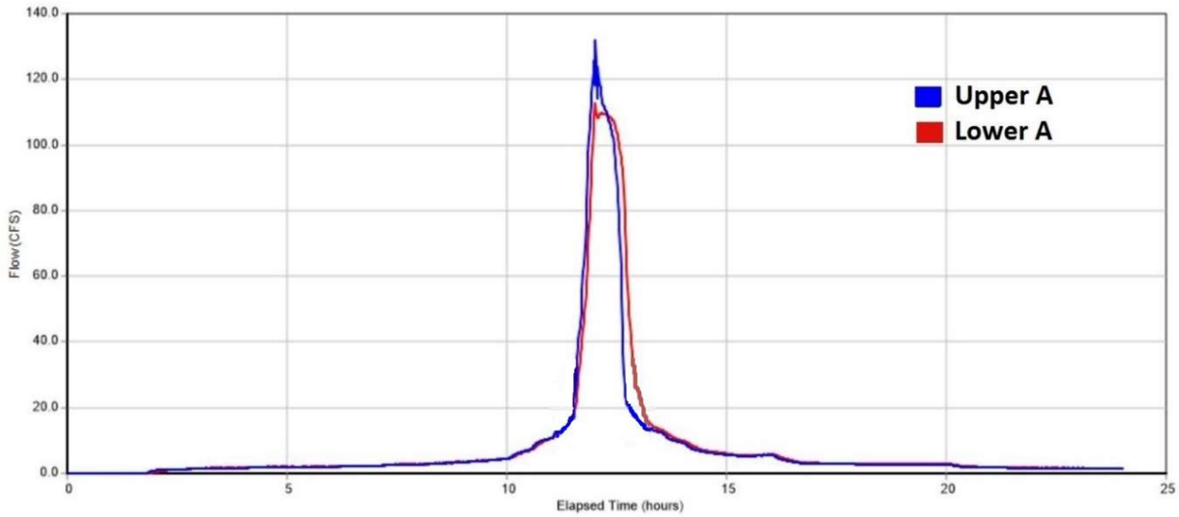

Figure 22: Instream Flow Reduction of due to Storage Unit One.

Nutrient Reduction

The nutrient removal rates were calculated using the default rates from the Chesapeake Stormwater Network study in Baltimore Co, MD, in 2003 that was detailed in 'Nutrient Removal Rates for Best Management Practices.' The calculation is based on total linear feet that will be daylighted. For this project, the total is 346 feet for each design option. Total current pipe is 450 feet but the stormwater must return underground for the last 104 feet to maintain the parking area north of the Forest Theatre.

Approved Removal Rates per Linear Foot of Qualifying Stream Restoration				
	TN	**TP**	**TSS**	Units
Removal Rate	0.02	0.0035	2.55	lb/ft/yr
Total Linear Feet to be restored	346	346	346	Ft
Total Reduction	**6.9**	**1.2**	**882.3**	**lb/yr**

Table 15: Total Rate of Nutrient Removed. ("Urban Stream Restoration" Good Diet for a Healthy Bay. Chesapeake Stormwater Network).

The data from the Chesapeake Stormwater Network is a doubtful baseline for estimating the total amount of nutrients and total suspended solids removed from the site because this project is not a stream restoration where cut banks and high erosion are found. Table 15 notes a high level of TSS removed from the site each year and this is not a practical estimation due to the smaller size of this project sub-watershed and the length of stormwater pipe when compared with the stream restoration project. Also, each design option has benefits and drawbacks that will probably affect the actual nutrient reduction rates.

One cubic yard of sandy loam soil with a 15% moisture content weighs approximately 2385lbs; therefore, an estimate of 10 ft^3/ year would build up in the project area if 890 lbs of nutrients (soil) are contained per year. This estimation is based on sloughing streambanks and the nutrient reduction Table 15 above; the total weight of nutrients reduced a year per linear foot and comparing that to the weight of sandy loam soil. At this rate, cleaning out the storage unit every five years with this estimate would lose less than 1% of storage capacity during the maintenance period. As stated earlier, sloughing banksides is not an issue for a daylighting project so these estimates are extremely high.

Effects on Big Valley Storage

Reducing the rate of runoff in the Forest Theatre project area will impact the volume of water to be stored in the upstream section of the stormwater system, the Big Valley Storage area. This section was modeled during the analysis of the Forest Theatre section. While there is an effect on the total amount of time high volumes were calculated, the existing infrastructure did not fail in the model for the 10-year, 24-hour storm event. These results are found in Appendix D.

Cost Comparison Analysis

Table 16 below shows a cost comparison of the four design options. The details of the cost estimates can be found in Appendix C.

Design Option Cost Estimates		
	Cost	Rank
Design Option 1: Simple Daylighting	$415,290	4
Design Option 2: Daylighting w/ One Wet Detention Basin	$374,309	2
Design Option 3: Daylighting w/ Two Wet Detention Basins	$377,186	3
Design Option 4: No action Alternative	$0	1

Table 16: Design Option Cost Estimates

Recommended Design Option

It is recommended that 'Design Option Two' be implemented for the Forest Theatre Daylighting project. Flow and velocity reduction make this project beneficial to treating the runoff. This design also maintains the user accessibility to the area which is in the interest for the Botanical Gardens and Forest Theatre users. Table 17 below show the results of each option.

	Reduce Peak Velocity/ Flow	Nutrient Benefits	Aesthetics	Low Running Cost/ Ease of Maintenance	Low Capital Cost	Scour	Rank
Option 1: Daylighting	Medium	High	Medium	High	Medium	Medium	2
Option 2: One Wet Detention Basin	High	High	High	Medium	Medium	High	1
Option 3: Two Wet Detention Basins	Medium	High	High	Medium	Medium	High	3
Option 4: No action alternative	Low	Low	Low	High	High	Medium	4

Table 17: Rank and Comparison of Each Design Option

CHAPTER 4: IMPLEMENTATION AND COST DETAIL

Introduction

This chapter details the process needed to implement the design that was chosen in Chapter 3. The permitting process, construction, total cost detail and cost-benefit analysis are discussed in detail. The majority of information in this section is from meetings with the ESD staff.

Review and Permitting

This is considered a relatively small project by the ESD and is likely to fall within the department's budget for maintenance, repairs, and project implementation. As such, only an internal review will be necessary, with no required administrative review at the municipal, county, or state level. The project will most likely be reviewed by Sally Hoyt, stormwater engineer with the ESD, the Battle Park Manager, Nick Adams, and the UNC Environmental Health and Safety Department (EHS). Additionally, if it is decided to implement the project, additional design will take place to review and finalize the conceptual designs presented in the 'Analysis' section of Chapter 3, and prepare contract plans and specifications.

Further design work will most likely not be conducted by ESD, but rather by an engineering firm that has a contract with the university. The ESD will submit a request for proposals from one of these firms whose bids would be assessed based on their total price bid. The firm that is awarded the bid will be responsible for, other than the additional design work, the production of construction documents and the carrying out of construction management.

Construction and/or maintenance of any kind that occurs in or around waterways of any type are subject to compliance with nationwide permits (NWPs) in coordination with NCDEQ and the US Army Corps of Engineers (USACE). Over 50 NWPs exist, and the necessary compliance depends on the type of project and the conditions under which it is undertaken. Due to the nature, size, and scope of the proposed project, it will most likely require NWP 3 – Maintenance. NWP 3 pertains to "The repair, rehabilitation, or replacement of any previously authorized, currently serviceable structure…" and allows for "…including the removal of material from the stream channel, must be immediately adjacent to the project or within the boundaries of the structure or fill…" (USACE, 2012). EHS will be responsible for coordinating any required nationwide permitting conditions. An erosion control permit will not be required because the area of impact will be less than one acre; however, an erosion control plan must be produced by the supervising engineer and approved by EHS.

Construction

The general construction process will begin in December during winter break as follows. A mini excavator will be used to remove the current stormwater pipe system from the Boundary St. and Country Club Rd. intersection to the end of the stormwater pipe underneath Parking Lot N5. The channel will then be excavated and widened according to the Design Option Two shown in the 'Design Options' section of Chapter 3. Excavated material will be hauled offsite and sediment runoff will be mitigated with silt fencing.

During construction, there will need to be a pumping system installed as a pump-around during storm events until the Forest Theatre project is complete. An intake will be located upstream of the project area where temporary piping will then transport stormwater water around the site to reenter the creek channel downstream of the project area.

When dirt work is completed each day, excavated banks will be stabilized with a biodegradable coconut fiber matting until the multicolored stonework can be installed in the channel and on the banks (Wiebke, 2016). Upon completion of excavation and stabilization, the banks of the channel will be lined with stonework and the area will be replanted with permanent trees, shrubs and grasses.

According to Nick Adams, the Battle Park Manager for the UNC Botanical Garden, the botanical garden staff will be responsible for all activities concerning the landscaped areas around the site. The funds for this aspect of the project will likely be supplied by the Botanical Garden's normal operating budget.

Due to the specialized nature of waterway construction, the project will most likely be implemented by experienced outside contractors familiar with this type of project. With only approximately 450 feet of channel affected, the limited size and scope of the project makes a prequalification process unnecessary. A utility survey should be conducted due to the significant earthwork needed as well as the relocation or temporary relocation of the power lines that run through the project area. Utility location services are provided by utility companies at no cost as a required component of the contractor's preconstruction due diligence.

The staging area for construction will be Parking Lot N5, the lot that is due North of the Forest Theatre and accessed from Boundary St. This will provide easy access to the site near the downstream end of the project while avoiding any issues with road traffic.

Scheduling

The timeline and schedule of the project will ultimately be decided by the construction contractor and the supervising engineer along with ESD and Botanical Garden staff.

Construction of the project will likely take three weeks depending on weather conditions and any unforeseen issues such as excavation of large rocks or equipment downtime. The ideal time of the year for the project to be implemented is during the winter break for a number of reasons. Most importantly, there is a reduced chance of heavy storm events in the winter which could disrupt the construction process by way of undesirable working conditions, flooding and reduced equipment access, as well as produce increase risks of bank erosion and other sources of sediment runoff. Public disruption will also be reduced if the project was implemented over winter break when campus is experiencing reduced traffic volume.

Public Disruption

The site is directly bordered to the south by the Forest Theatre which would need to restrict access during construction for safety purposes; however, few events are held in the theatre during the winter months. A pedestrian detour plan will need to be implemented by the contractor, consisting mainly of detour signs on the walking path and blaze orange safety fencing along Boundary St and parking lot N5. It will be the responsibility of the UNC Department of Public Safety (DPS) to notify the relevant parties affected by the placement of the equipment staging area and it may be necessary to reimburse UNC employees if assigned parking spaces are affected.

Resource Requirements

The resources required for the proposed project include silt and safety fencing, coconut fiber matting, vegetation, concrete and rebar, mortar, field stone for the headwall and stonework. As previously explained, a pump around system will also be necessary. In addition to the construction materials described above, the project will require construction equipment such as a mini excavator, crane for demolishing the current stormwater system and installing the new box culvert sections and dump truck for removing the excavated material.

Operation and Maintenance

The proposed solution to daylighting the Battle Branch stormwater drainage section is not mechanical but could create an additional maintenance burden on botanical garden staff. Channel maintenance will be necessary, but it will not require rigorous annual maintenance. Annual maintenance will include removing large debris after large rainfall events and removing urban wastes, such as cups and paper bags that are common in the area, from the channel area. This will not create any additional maintenance from the Botanical Garden staff.

The maintenance to remove sediment from the storage unit every five years will require additional equipment such as an excavator and dump truck. This is estimated to take only one day since the load is estimated to be less than on small truck load.

Costs

The cost of channel design, construction and maintenance are computed below. The conceptual level design calculations used for each design option to estimate costing parameters are presented in Appendix A.

Construction costs include site preparation, earthwork, sediment and erosion control, bank and bed stabilization, and site management. Site preparation cost is the installation of safety fencing to divert pedestrian traffic.

Earthwork costs include demolition, excavation, and grading. Demolition refers to removal of the existing stormwater pipe and transport of the demolished pipe. For the cost calculation, the stonework was assumed to be one-foot-thick on average. Excavation includes the removal of stream material in order to achieve the proposed geometry and was calculated by taking the difference in volume between existing, estimated topography and proposed channel cross sections over the length of the channel. After excavation, the channel bed and banks will be graded to ensure that the contour is consistent with the selected design and then lined with stonework. Erosion and storm control includes silt fencing to protect the daylighted stream bed and the pump around that was discussed above.

Materials and installation include the crane that will be needed to install the culvert sections that span the parking lot and the materials such as, stone, vegetation and parking displacement that will occur during the project implementation.

The multicolored smoothed stone or stonework is a significant portion of the costs of this project. The vegetation will be determined by the botanical garden staff and the average is cost is estimated from similar projects. The temporary fencing will be used to direct pedestrian traffic around the project area and limit access to the Forest Theatre. The headwall will be will be concrete with a stone façade.

It was estimated that construction equipment and traffic will use seven of the 14 ‘non-gated’ parking spaces and the reserved spot due to its location in the south section of the lot. The daily value was calculated from UNC-Parking hourly rates.

Mobilization and demobilization of equipment and materials is estimated to be about 10% of total construction costs, or $20,931. Finally, it is estimated that the additional project design and construction management will cost 30% of total project cost or approximately $82,885.

Benefits of Nutrient Removal

The total estimated cost of implementing the selected design is $374,170. An integral part of the ESD desire to implement this project is nutrient reduction that can earn nutrient credits. Nutrient costs were calculated by estimating the weight of nutrients- nitrogen and phosphorus- retained on the project site for the duration of the project lifespan, 30 years then divided by the total capital cost of the project. These values are far from exact and represent an excessive estimate as they are believed to reflect reduced “sloughing of channel banks” in stream restoration that will not occur in this project.

Approved Removal Rates per Linear Foot of Qualifying Stream Restoration			
	TN	**TP**	Units
Removal Rate	0.02	0.0035	lb/ft/yr
Total Linear Feet to be restored	346	346	ft
Total Reduction	**6.9**	**1.2**	**lb/yr**
Nutrient Costs per year	**$10,619**	**$1,847**	**$/yr**

Table 18: Nutrient Costs Per Year (Berg, Burch et al. 2015).

Cost-Benefit Analysis

Cost-benefit analyses are performed in order to determine if a project offers net economic benefits. The Forest Theatre project produces two benefits in addition to those of maintaining the current good drainage of the area- nutrient removal benefits and aesthetic benefits. Only nutrient removal benefits are calculated for this analysis due to the fact that aesthetics are inherently difficult to quantify.

Annual nutrient removal benefits are estimated to be $12,466. This is the estimated annual value of nutrients removed from stormwater runoff in the project area. It was calculated by finding the total value of nutrients for the 30-year project duration by removing a total of 8.1

lbs of nitrogen and phosphorus per year. Equation 1 was used to determine the net present value, NPV, of costs for the time period, *n*, of 30 years at a discount rate, *i*, varying from 2% to 5%. The discount rate shows that benefits in the future are worth less than the same benefits in the present, because of inherent uncertainty, time preference for benefits, and the opportunity cost of capital.

$$NPV = \frac{FV}{(1+i)^n}$$

Where:

NPV = Net Present Value
FV = Future Value
i = Discount Rate
n = Number of years from Present

Equation 1: Net Present Value formula

Figure 23 shows the sensitivity analysis of a variable discount rate. With a 2% discount rate, it can be seen that the project does not become financially feasible until year 44 and the estimated lifespan of the project is 30 years. This analysis does not consider all of the benefits that are possible for this project, most notably aesthetic appeal, which is difficult to quantify. Aesthetic value would make this project much more appealing from a financial standpoint.

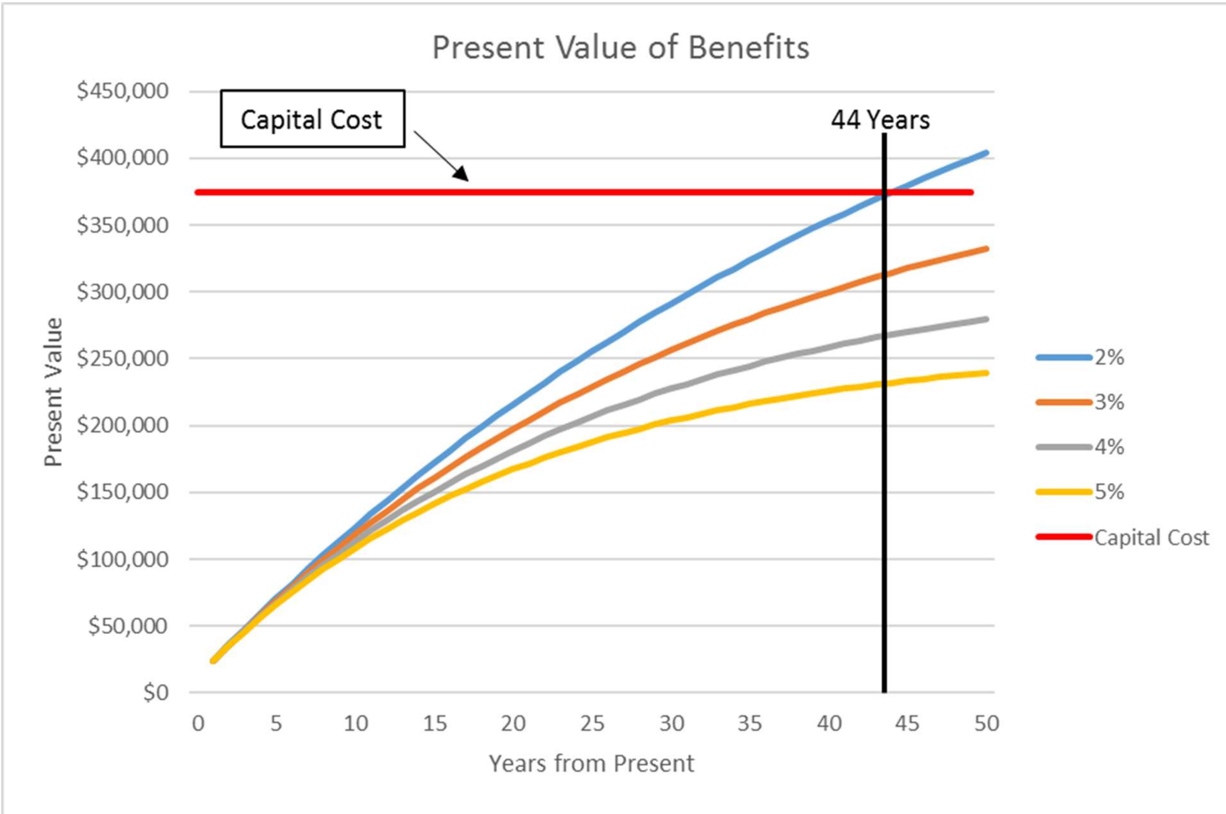

Figure 23: Present Value of Benefits with a Variable Discount Rate

CHAPTER 5: CONCLUSION

As stated in Chapter 4, the cost-benefit analysis does not show this project to be economically justified solely in terms of the economic benefit of nutrient reduction; however, there are other benefits to the project. Aesthetic benefits are difficult to quantify but significant, as daylighting this section of stormwater drainage would create a stream corridor from Battle Park to the UNC Arboretum. This would allow someone to walk from the forest of Battle Park, along the daylighted section of Forest Theatre, onto the Big Valley Storage daylighted section and into the Arboretum. This could create a higher value for the area by incentivizing more foot traffic. A serious review of this project by an independent landscape architect to assess the aesthetic benefits may be appropriate if needed to decide on whether to adopt Option 2 or stay with Option 4 (no action.)

Fortunately, there is no worry of flooding in excess of accepted UNC and Chapel Hill design standards at this time for this section of stormwater drainage. No damage is currently occurring to the Forest Theatre due to flooding so this project is not a high safety concern at this time; however, future development that reduces permeable surfaces could impact the volume of runoff that is received in this reach. Currently, there is no mention of this in the UNC Master Development Plan.

Aging infrastructure could be another incentive to make this project more feasible. As the concrete pipes continue to age and the high velocities continue to scour this section, there would be a more imminent need to replace them if they were to fail. A sensitivity analysis on the 1-year, 2-year and 5-year storms, EPA-SWMM shows approximately one hour during each event where scour is occurring in the lower reach. Failure of this last section of stormwater pipes would most certainly cause flooding to the Big Valley Storage area.

A more accurate analysis of nutrient runoff would most likely make this project less economically attractive. By studying current conditions through the Forest Theatre, an accurate value of stormwater nutrients can be calculated. Once the project is complete, if it is implemented, the nutrient values of the stormwater could be studied once again to compare the values to determine if there is any nutrient reduction benefit gained. Increasing interest in reducing nutrients to Jordan Lake might make this project a higher priority for UNC land planners and the estimates used in the project analysis could prove to be inaccurate in the future.

Lastly, there could be a more suitable option to nutrient reduction than daylighting that was not explored in this report. It could involve a better management of nutrients before they reach the storm sewer. Possible options include, utilizing permeable pavement, a system of grassed swales and berms that increase stormwater absorption into soils or a more extensive network or underground water storage.

APPENDIX A: RAINFALL DATA

Precipitation Frequency Estimates (inches/hour)							
Duration	Average recurrence interval (years)						
	1	2	5	10	25	50	100
5-min	4.93	5.81	6.7	7.38	8.11	8.62	9.07
10-min	3.94	4.64	5.36	5.9	6.46	6.86	7.21
15-min	3.28	3.89	4.52	4.98	5.46	5.79	6.07
30-min	2.25	2.69	3.21	3.61	4.04	4.36	4.65
60-min	1.4	1.69	2.06	2.35	2.69	2.95	3.2
6-hr	0.359	0.433	0.534	0.62	0.73	0.821	0.913
12-hr	0.211	0.254	0.316	0.368	0.438	0.497	0.557
24-hr	0.123	0.149	0.186	0.215	0.255	0.286	0.318

Table 19: Rainfall Frequency for Chapel Hill, NC. Source: NOAA, 2013.

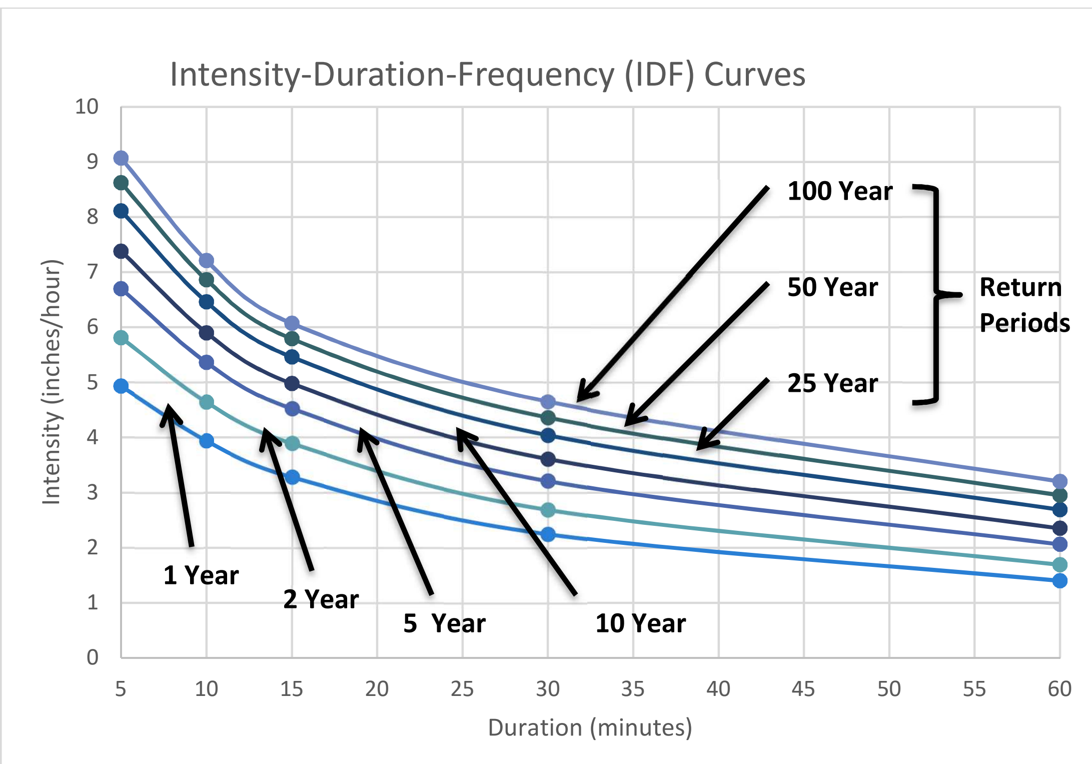

Figure 24: IDF Curve for Chapel Hill, NC (Source: NOAA, 2013).

APPENDIX B: POSSIBLE FORMS OF VEGETATION

Scientific Name	**Common Name**	**Description**
Trees		
Celtis laevigata	Southern hackberry	Medium sized deciduous tree with characteristic warty bark.
Nyssa sylvatica	Blackgum	Understory tree, red foliage in fall, black drupes
Platanus occidentalis	American sycamore	Fast growing broad-leafed deciduous tree
Quercus michauxii	Swamp chestnut oak	Large canopy oak with chestnut-like leaves
Diospyros virginiana	American persimmon	Understory tree; large fruits; good wildlife
Shrubs:		
Amelanchier arborea	Downy Serviceberry	A small tree or shrub with a narrow, round crown and white elongate petals at the branch tip. Up to 10 meters tall
Cephalanthus occidentalis	Buttonbush	Shrub-tree, white globe-shaped flowers, red foliage and seed heads in fall
Cornus amomum	Silky dogwood	Spreading, deciduous shrub; inflorescence a cyme of small white flowers; blue fruits
Corylus americana	American hazelnut	Spreading understory shrub bearing long catkins in late winter and sweet edible nuts in August-September
Hibiscus mocheutos	Eastern rosemallow	
Rhododendron periclymenoides	Pink azalea	
Magnolia tripetala	Umbrella magnolia	
Lindera benzoin	Spicebush	Shrub with aromatic stems and leaves, red stems and red fall foliage
Herbs/ graminoid:		
Lobelia cardinalis	Cardinal flower	Tall leafy herb, showy red flower spikes; attracts butterflies, humming birds
Scirpus sp.	sedges	aquatic, grasslike species
Chasmanthium latifolia	River oats	Native woodland grass with showy, flat seed heads
Vernonia sp.	ironweed	Robust perennial herb, tall leafy stem, numerous purple disk flowers
Carex sp.	Sedges	
Asclepias syriaca	Milkweed	
Impatiens capensis	Jewelweed	

Table 20: Vegetation Options for Forest Theatre Project. Description courtesy of Mellowmarsh Farms (http://mellowmarshfarm.com/native-plants-grasses-trees-seeds/)

APPENDIX C: COST ESTIMATES

The values for each cost analysis come from a past ESD implemented project (CIP-708, McCauley St Detention) and meeting with ESD staff.

Design Option One Cost Analysis

	Quantity	Unit	Cost	Total
Earthwork				
Excavation	2,915	CY	$20	$58,300
Pipe Removal	450	LF	$25	$11,250
Erosion/ Storm Control				
Construction entrance, stabilized	1	Ea.	$1,500	$1,500
Natural Fiber Erosion control matting		SY	$5	$0
Pump Around (storm)	15	Day	$1,400	$21,000
Silt fence	150	LF	$3	$375
Temporary seeding/mulch	250	SY	$3	$750
Materials and Installation				
Crane	2	Day	$4,000	$8,000
Reinforced Concrete Precast Box Culvert, 4'x3'x8'	13	Sections	$1,123	$14,599
Stone and sand				
Stonework	1,063	CY	$100	$106,311.11
Vegetation				
Tree protection	5	Ea.	$100	$500
Trees, shrubs, herbaceous perennials	150	SY	$8	$1,200
Permanent Grass Seed	625	SY	$5	$3,125
Walls				
Temporary Fence	300	LF	$4	$1,200
Stone headwall				$10,000
Temporary Loss of Parking Spaces				
non-gated- 14 spaces	15	days	$224	$3,360
Reserved- 1 space	15	days	$36	$540
Total				**$242,010**
Mobilization and Demolition (10% of subtotal)				$24,201.01
Contingency (20% of Project)				$53,242.22
CONSTRUCTION COST				**$319,453**
Design (20% of Construction Cost)				$63,890.67
Construction Admin/ UNC PM Fee (10% of Construction Cost)				$31,945.33
TOTAL COST				**$415,289.35**

Table 21: Design Option One Detailed Cost Estimates

Design Option Two Cost Analysis

	Quantity	Unit	Cost	
Earthwork				
Excavation	2,255	CY	$20	$45,100
Pipe Removal	450	LF	$25	$11,250
Erosion/ Storm Control				
Construction entrance, stabilized	1	Ea.	$1,500	$1,500
Pump Around (storm)	10	Day	$1,400	$14,000
Silt fence	1,100	LF	$3	$2,750
Temporary seeding/mulch	250	SY	$3	$750
Materials and Installation				
Crane	2	Day	$4,000	$8,000
Reinforced Concrete Precast Box Culvert, 4'x3'x8'	13	Sections	$1,123	$14,599
Stone				
Stonework	874	CY	$100	$87,407
Vegetation				
Tree protection	5	Ea.	$100	$500
Trees, shrubs, herbaceous perennials	200	SY	$8	$1,600
Permanent Grass Seed	500	SY	$5	$2,500
Walls				
Temporary Fence	800	LF	$4	$3,200
Stone Headwall				$10,000
Temporary Loss of Parking Spaces				
non-gated- 14 spaces	15	days	$224	$3,360
Reserved- 1 space	15	days	$36	$540
Total				**$207,056**
Five Year Maintenance	1	day	$2,500	$2,500
Mobilization and Demolition (10% of subtotal)				$20,706
Contingency (20% of Project)				$45,552
CONSTRUCTION COST				$273,314
Design (20% of Construction Cost)				$54,663
Construction Admin/ UNC PM Fee (10% of Construction Cost)				$27,331
TOTAL COST				**$374,309**[3]

Table 22: Design Option Two Detailed Cost Estimates

[3] Notice that 'Design Option 2' is significantly cheaper than 'Design Option 1.' This is due to the fact that a much larger volume of soil is removed in 'Design Option 1' because there is no storage unit.

Design Option Three Cost Analysis

	Quantity	Unit	Cost	Total Cost
Earthwork				
Excavation	2,476	CY	$20	$49,520
Pipe Removal	450	LF	$25	$11,250
Erosion/ Storm Control				
Construction entrance, stabilized	1	Ea.	$1,500	$1,500
Inlet protection	1	Ea.	$100	$100
Pump Around (storm)	10	Day	$1,400	$14,000
Silt fence	1,100	LF	$3	$2,750
Temporary seeding/mulch	250	SY	$3	$750
Materials and Installation				
Crane	2	Day	$4,000	$8,000
Reinforced Concrete Precast Box Culvert, 4'x2'x8'	13	Sections	$888	$11,544
Stone and sand				
Stonework	907	CY	$100	$90,700
Vegetation				
Tree protection	5	Ea.	$100	$500
Trees, shrubs, herbaceous perennials	200	SY	$8	$1,600
Permanent Grass Seed	350	SY	$5	$1,750
Walls				
Temporary Fence	800	LF	$4	$3,200
Stone Headwall				$10,000
Temporary Loss of Parking Spaces				
non-gated- 14 spaces	15	days	$224	$3,360
Reserved- 1 space	15	days	$36	$540
Total				**$211,064**
Five Year Maintenance	1	day	$2,500	$2,500
Mobilization and Demolition (10% of subtotal)				$21,106
Contingency (20% of Project)				$46,434
CONSTRUCTION COST				$278,604
Design (20% of Construction Cost)				$55,721
Construction Admin/ UNC PM Fee (10% of Construction Cost)				$27,860
TOTAL COST				**$377,186**

Table 23: Design Option Three Detailed Cost Estimates

APPENDIX D: DESIGN IMPACTS ON BIG VALLEY STORAGE

Appendix D shows the effects that the Forest Theatre project will have on the stormwater system that is directly upstream from this project area, 'Big Valley Storage.' 'Big Valley Storage' is a daylighting project that was completed in January 2016.

Current Status:

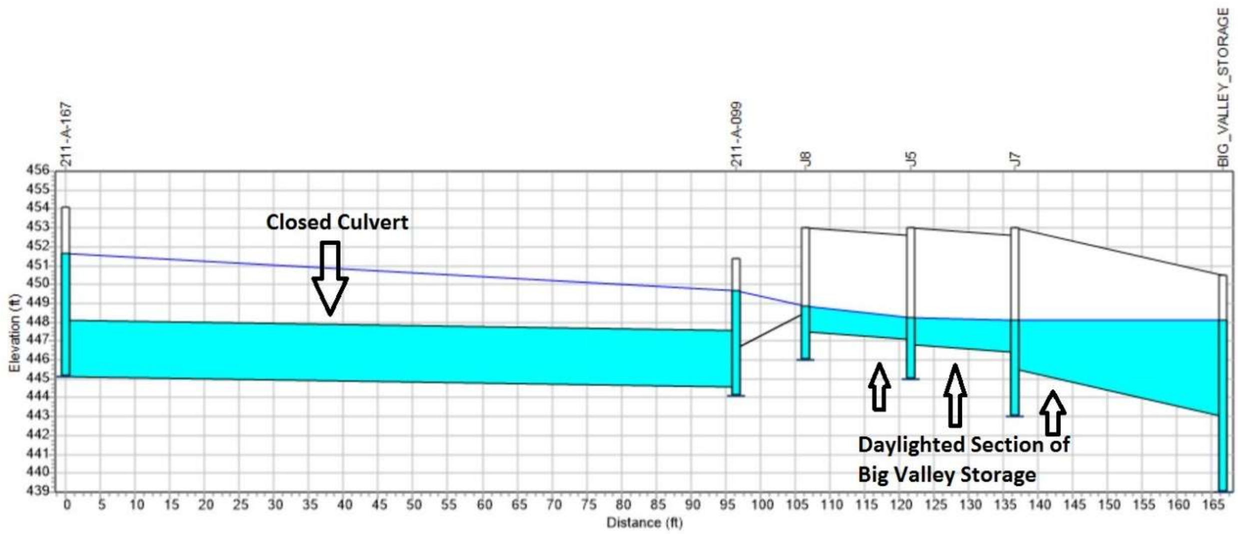

Figure 25: Current Flow Profile of Big Valley Storage

Impacts on Big Valley Storage from Design Option One:

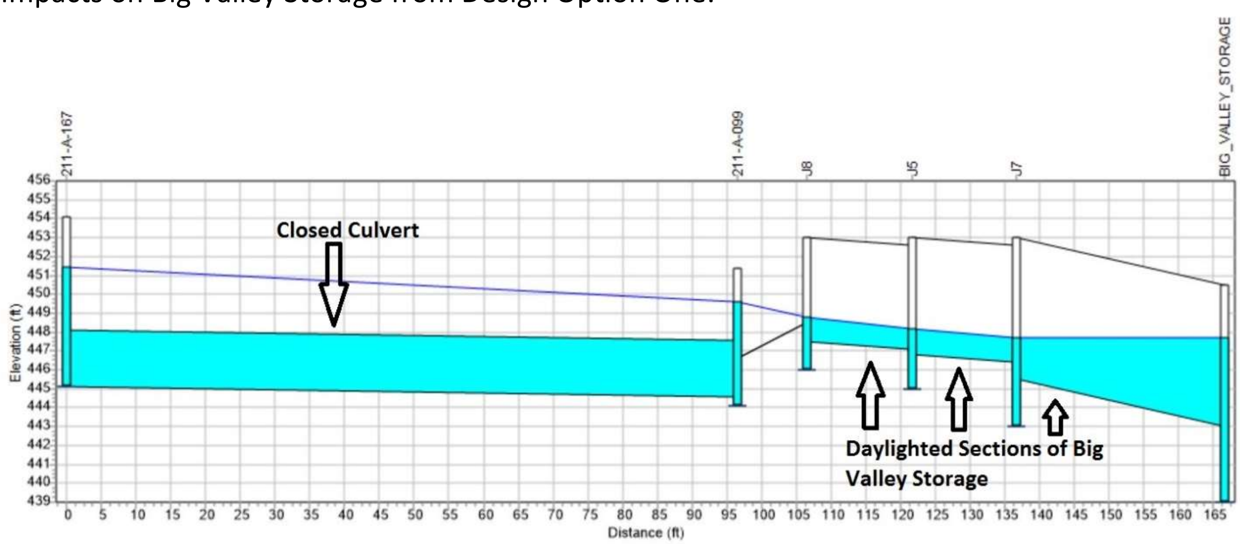

Figure 26: Flow Profile of Big Valley Storage if Design Option One Implemented

Impacts on Big Valley Storage from Design Option Two:

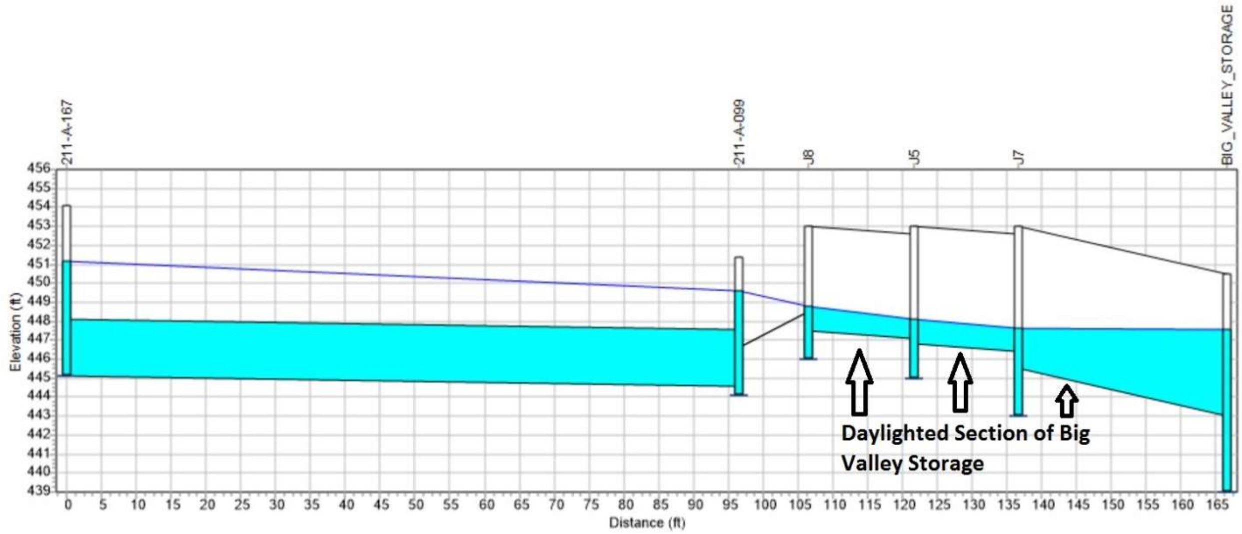

Figure 27: Flow Profile of Big Valley Storage when Design Option Two Implemented

Impacts on Big Valley Storage from Design Option Three:

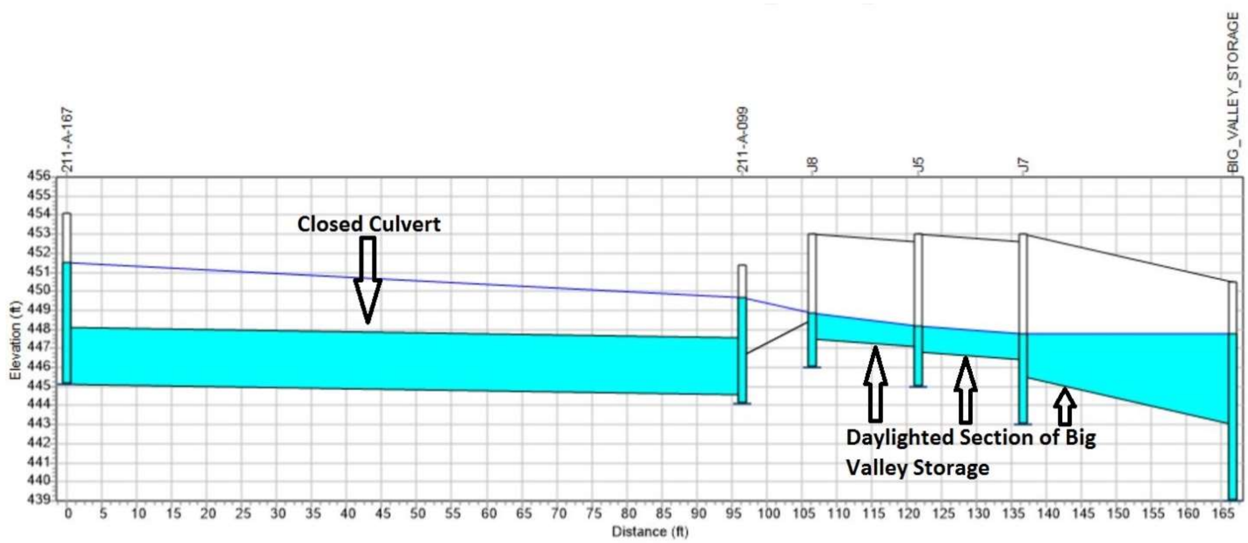

Figure 28: Flow Profile of Big Valley Storage if Design Option Three Implemented

APPENDIX E: CONDUIT NAMES AND CORRESPONDING SWMM LABELS

For ease of labelling and understanding, SWMM labels were changed in this report for the reader to more easily understand the layout of each design. Table 18 shows the report names for each SWMM label as they are represented in each model.

Design Option One	
Report Name	SWMM Label
Upper Reach	25824
Lower Reach	25825
Culvert	C2

Table 24: Design Option One Labels

Design Option Two	
Report Name	SWMM Label
Upper A	C4
Upper B	C2
Storage 1	C8
Lower	C-5
Culvert	C3

Table 25: Design Option Two Labels

Design Option Three	
Report Name	SWMM Label
Upper A	C4
Upper B	C10
Storage 1	C42
Lower A	25825
Lower B	C22
Storage 2	C41
Culvert	C21

Table 26: Design Option Three Labels

REFERENCES

2013 SWMM Model Documentation: Cole Springs, Battle Branch and Friday Center; Stormwater Master Plan, Phase II." Rummel, Klepper and Kahl, LLC.

American Society of Civil Engineers (ASCE). (1982). Gravity Sanitary Sewer Design and Construction, ASCE Manual of Practice, No. 60. New York, NY.

Berg, Joe, Josh Burch, *et al*. (2014) "Recommendations of the Expert Panel to Define Removal Rates for Individual Stream Restoration Projects." Chesapeake Stormwater Network and Center for Watershed Protection.

Chesapeake Stormwater Network (2015). *Good Diet for a Healthy Bay*. Annapolis, MD.

Forest Theatre Preservation Survey, Form 431. University of North Carolina, Energy Services Department.

Harman, W., R. Starr, M. Carter, K. Tweedy, M. Clemmons, K. Suggs, C. Miller. 2012. A Function-Based Framework for Stream Assessment and Restoration Projects. US Environmental Protection Agency, Office of Wetlands, Oceans, and Watersheds, Washington, DC EPA 843-K-12-006. Web < http://www.fws.gov/chesapeakebay/StreamReports/Stream%20Functions%20Framework/Final%20Stream%20Functions%20Pyramid%20Doc_9-12-12.pdf>

Hunt, William F, Lord, William G. 2001. Urban Waterways: Bioretention Performance, Design, Construction and Maintenance. North Carolina Cooperative Extension Service.

James, W., L. Rossman & W.R. James. (2010). User's Guide to SWMM 5. Computational Hydraulics International, Guelph, Ontario, Canada.

Jordan Lake- Measuring Conservation Success. (2007). The Environmental Management Commission. Web<https://conservationsuccess.wikispaces.com/file/view/10.doc>

Jordan Water Supply Nutrient Strategy: Stormwater Requirements for State and Federal Entities, Section 15A NCAC 02B.0271. Town of Chapel Hill, Stormwater Management Master Plan. Web < http://reports.oah.state.nc.us/ncac/title%2015a%20-%20environmental%20quality/chapter%2002%20-%20environmental%20management/subchapter%20b/15a%20ncac%2002b%20.0271.pdf>

Mellowmarsh Farm (2016). "Native Plants by Category" accessed at http://mellowmarshfarm.com/native-plants-grasses-trees-seeds/.

North Carolina Division of Water Quality. (2007). Stormwater Best Management Practices Manual.

NOAA (National Oceanic and Atmospheric Administration). 2013. "Precipitation Frequency Data Server." Hydrometerological Studies Design Center.

National Park Service. “Giving New Life to Streams in Rural City Centers”. Indian Creek Brochure. Web < http://www.nps.gov/ncrc/rivers/projpg/DAYLIGHT.PDF>

Pinkham, Richard. “Daylighting: New Life for Buried Streams”. Rocky Mountain Institute, Colorado, 2000. Web < www.rmi.org>

RK&K and Biohabitats Inc. (2013). *Stormwater Master Plan Study, Phase II: 2013 SWMM Model Documentation.* Raleigh, NC.

Stormwater Best Management Practices Handbook. North Carolina Department of Environment and Natural Resources. July 2007. Web <http://portal.ncdenr.org/web/lr/bmp-manual>

Stormwater Performance Criteria, Design Standards and Procedures, University of North Carolina at Chapel Hill. June 2010.

“Stream Restoration Nutrient Credit Standards & Design Conditions”. Prepared by NCDEQ. Not a published document but given as a reference by Sally Hoyt.

Van Houtven, George, Loomis, Ross, Baker, Justin, Beach, Robert, Casey, Sara. “Nutrient Credit Trading for the Chesapeake Bay: An Economic Study.” RTI International, Research Triangle, NC. May 2012. Web http://www.chesbay.us/Publications/nutrient-trading-2012.pdf

Water Environment Federation. (2012). *Design of Urban Stormwater Controls* (Manual of Practice, 87). New York: McGraw-Hill Professional.