Green Stormwater Infrastructure Retrofit Design for Duluth Middle School

Harmonia Engineering

Prepared for: Gwinnett County Department of Water Resources
Gwinnett County, Georgia

Submitted to:
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Abstract

A design was prepared for the Gwinnett County Department of Water Resources to reduce and treat stormwater runoff at Duluth Middle School, a public school in Georgia. The design prioritizes runoff reduction, water quality improvement, and public visibility. GIS database information and as-built site drawings were reviewed, and a site visit was conducted after a storm event. A total of 27 best management practices (BMPs) were initially reviewed, and five alternatives were selected for an iterative design process. The runoff was modeled, and the BMPs were sized to capture the first 1" of rainfall, treat runoff for 85% of annual storms, and decrease TSS concentrations by 80%. The designs included (i) a bioretention basin at the bus loop, (ii) pervious pavement in the carpool lot, (iii) StormTrees™ in the carpool lot islands, (iv) a dry-enhanced swale in the greenspace along the entrance drive, and (v) stormwater planters fed by disconnected roof downspouts. Based on the client's goals and budget, the bioretention basin, dry-enhanced swale and stormwater planters were recommended for implementation with an opinion of probable cost of $477,000 with contingency. Public outreach was incorporated into the project, to provide for public education on the importance of protecting local watersheds.

Summary of Project Team Effort

The interdisciplinary team was composed of four undergraduate students from the Georgia Institute of Technology, at the school of Civil and Environmental Engineering (CEE). As of December 2023, all four team members consisting of Makaela Edmonds, Isabella Hernandez, Lucy Bricker, and Olivia Verret will have completed B.S. degrees in Environmental Engineering. In addition, Makaela Edmonds and Olivia Verret are expected to complete minors in Sustainable Cities, and Lucy Bricker is expected to complete a minor in Biology. In the spring of 2024, Lucy Bricker will also have completed an M.S. in Environmental Engineering. The team's client was the Gwinnett County Department of Water Resources (DWR), in Georgia.

Makaela Edmonds acted as the project lead, which entailed being the main point of communication with the client and ensuring the team was progressing according to the project schedule and deadlines. She also performed the cost estimation for the alternatives, created the hydrocad modeling, and completed the required GIS work. Lucy Bricker completed the calculations for alternatives one through three, and Isabella Hernandez completed calculations for alternative four and the add-on design element. Calculations for sizing requirements of all designs were based on methods outlined by the Gwinnett County Stormwater Management Manual, which was adapted from the Georgia Stormwater Manual. Method Technical Release 55 (TR-55) was used as the primary hydrological method, and was adapted slightly for application in urban environments. Lucy Bricker also completed the CAD modeling, led the initial steps for the hydrocad analysis, and assisted with the cost estimation processes. Olivia Verret completed the water quality calculations, led the public outreach component, and recorded notes from meetings. All members contributed to the existing conditions analysis, discussions at weekly client meetings, technical writing, editing, and report formatting.

Multiple people at the Gwinnett County DWR provided assistance throughout the design process. Heather Gacek was the main contact, and James Grimes and Rachel Jones provided additional support and feedback. Faculty from Georgia Tech's CEE department also offered fundamental guidance throughout the process. Professor Sharon Just was the main advisor, offering support through weekly check-in meetings with the team, lectures and technical advice. Dr. Lisa Rosenstien provided feedback on technical writing and presentation. Dr. Eric Marks and Dr. Michael Rodgers provided their feedback on client relations and lectures for cost estimation. Gregg Novick from Porous Technologies, LLC. and Paul Lorio from StormTree offered data for product details for pervious concrete, and tree planters, respectively.

1.0 Introduction

1.1 Project Background

Beginning in 2000, the Gwinnett County Department of Water Resources (DWR) instituted a Watershed Protection Plan (WPP) to focus on the prevention, protection, and restoration of its watersheds. In 2019, the plan expanded to incorporate green stormwater infrastructure (GSI). Two key goals of the WPP include (1) implementing new and retrofitted Low Impact Development-Green Infrastructure (LID-GI) practices throughout the county, and (2) developing design guidance and performance standards for stormwater Best Management Practices (BMPs) for Gwinnett County. Six county-owned sites have been identified as candidates for GSI implementation. Duluth Middle School was identified as one of the sites that would benefit most from implementing GSI to decrease stormwater runoff, and was selected for development of design upgrades.

1.2 Project Location

Duluth Middle School is a public school in Duluth, a city in Gwinnett County, Georgia, in the northeastern region of Metro Atlanta and falls within the Chattahoochee River 4 subwatershed. The map showing the site location, denoted by a red star, is shown in Figure 1.

Figure 1: Site Location in the Metro Atlanta Area (Loftin, 2020)

1.3 Problem Statement

Gwinnett County Department of Water Resources selected Duluth Middle School as a candidate for a stormwater improvement project through a county-wide watershed characterization assessment. This site's subwatershed was identified as a priority for restoration efforts. Additionally, this site selection provides an opportunity for a highly visible and publicly accessible green stormwater infrastructure demonstration project. Excess stormwater runoff observed at the site negatively impacts the water quality of the Chattahoochee River watershed with respect to its total suspended solids (TSS) and metal loading. Designs that solve existing drainage issues on site while also improving the quality of water leaving the site will serve as a co-benefit of the project for all stakeholders.

1.4 Project Constraints

The client required any upgrade to designs be constrained to the school site, and indicated the selected approach should utilize existing stormwater pipes and inlets if possible. This is a retrofit project, so there is a limit on what infrastructure can be implemented onto the existing sites. Structural changes to the school building, including rooftop infrastructure, were to be avoided. Considering that this is a high-traffic site, GSI that can be performed in a three-month time period over the school summer break were prioritized in order to minimize interference with student life.

1.5 Project Objectives

This project has two main objectives. The first objective is to contribute to Gwinnett County's goal of improving the water quality of its watersheds. This objective will be met by implementing GSI designs at Duluth Middle School that are designed to (1) retain or reduce the first 1.0-inch of rainfall on the site and (2) reduce the average annual post-development TSS loadings by 80%.

The second objective is to increase public understanding of the importance of protecting and improving water quality. This site has been selected in part because the school is an accessible point of outreach for both community organizers and school members.

2.0 Existing Conditions

2.1 Site Evaluation and Design Constraints

Duluth Middle School is located on a 15.5-acre parcel of publicly owned land. The main components of the parcel are the school campus, a detention pond west of the school, and a county bus storage lot south of the school as seen in Figure 2. Per Gwinnett DWR's request, the scope of the project is restricted to visible, easily accessible sections of the school campus. The bounds of this project therefore include the entrance drive, the bus loop, and the carpool lot. This project excludes the field on the north end and the bus storage lot on the south end of the parcel.

Figure 2: Site Layout (Esri, n.d.)

The site's elevation and wooded areas separate it from surrounding developments and major roads; therefore, only the stormwater that falls in its boundaries will be considered. There is an existing stormwater system consisting of piped downspouts, yard inlets, and catch basins, which all drain to an interconnected stormwater pipe system. All the stormwater in the system is drained to an existing detention pond, located at a low point at the west end of the property.

The soil across the site is a variation of Madison clay-loam soil groups, which can be classified as hydraulic soil group C. This soil type has a slow infiltration rate, which exacerbates soil oversaturation and ponding during rainfall events. Detailed soil information is described in Appendix A.

In February 2023, members of Harmonia met Gwinnett County DWR representatives at Duluth Middle School and performed an initial site evaluation. The group identified areas of pooling from a recent storm event, and notable soil erosion due to runoff. These problems were prominent in five primary problem areas: the two school entrances, the bus loop, the school entrance drive and its greenspace, and the carpool lot. Figure 3 shows images of erosion and puddling observed during the site visit.

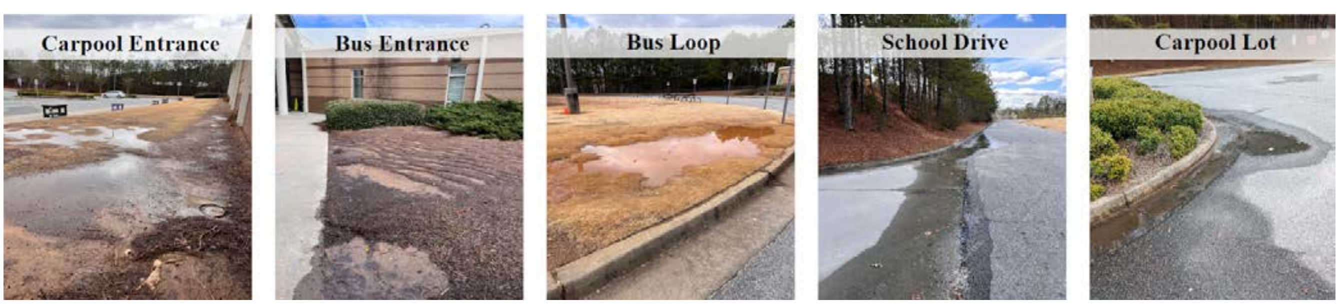

Figure 3: Puddling and Soil Erosion Found During the Site Visit

2.2 Pre-design Hydrology Analysis

All topography and existing infrastructure, such as existing stormwater and sewer lines, were evaluated based on the Gwinnett GIS database and As-Built site drawings (Gwinnett County GIS, 2020; Eberly, 2002). Based on this information, the flow paths of the water along the site were determined, as shown in Figure 4. The runoff's longest flow paths before reaching an inlet are shown in dark red arrows, with their corresponding lengths.

Figure 4: Flow Path Lengths per Basin (Esri, n.d.)

After evaluating the direction and flow path of runoff and the topography of the site, five drainage basins were delineated. Each drainage basin is delineated based on the water flowing into existing inlets and pipes as shown in Figure 5. Every drainage basin has an inlet within its area boundary. Drainage Basins 2 through 5 are addressed within the project design. Drainage Basin 1 was omitted due to the water flowing towards the back of the school and the small area, minimizing its potential impact.

Figure 5: Drainage Basins for Duluth Middle School (Esri, n.d.; Gwinnett County GIS, 2020)

To assess the extent of rain runoff on the site, the team determined the total impervious area for the site. A high percentage of impervious area reduces the area where infiltration can occur and thus increases the overall volume of surface runoff.

The surface runoff targeted in this project is limited to the runoff that drains on site, and into the detention pond. The driveway entering the school property, and the green space in the southwestern section of the property drain into a stormwater inlet on Pleasant Hill. The Pleasant Hill inlet is outside the limits of the site, therefore that runoff is excluded from the scope of this project. Runoff from the building rooftop was evaluated separately, because the downspouts drain directly to a stormwater line and runoff from the roof has low TSS and metal loads. Specifically, the rooftop flows were evaluated for add-on planters as discussed later in this report.

The percent of impervious area, percentage of grassy area, and local soil types were used to calculate a composite curve number (CN) based on the Gwinnett County Stormwater Management Manual (GCSMM). The hydraulic soil data for the site was obtained from GIS data provided by Gwinnett County. The five drainage basins have a total of 70% impervious area, and the rest lies on Madison loam soil. The soil varies from 2% to 45% slopes across the site, with varying degrees of erosion. Full descriptions of the soil types, and their distribution across the site are found in Appendix A. The soil on the site falls within hydraulic soil group C.

The paths across the impervious and pervious areas of each basin were considered separately, with separate coefficients and parameter requirements. For the impervious surfaces, the longest potential flow paths were drawn from the furthest extent of each basin to the outlet within each basin, as seen in Figure 4. For the pervious surfaces, the limiting length of flow was instead calculated based on National Engineering Handbook Part 630 due to their shallow slopes (National Engineering Handbook, 2010). Assuming that sheet flow occurs over a maximum of 100 ft, the time of sheet flow, and the time of shallow concentrated flow pervious and impervious sites were summed together to determine a time of concentration (T_C) for each basin. The 1.2-inch-24-hour storm was used to estimate the time of concentrations, according to the GCSMM. The composite curve number, area in square feet, percent impervious area, and time of concentration (T_c) for each drainage basin are shown in Table 1.

Table 1: Pre-Design Basin Parameters

Basin	Site Area (SF)	% Impervious	T_c (min)	Composite CN
Basin 1	16,631	81.41	6.57	93.54
Basin 2	61,784	86.75	6.04	94.82
Basin 3	40,122	79.42	11.64	93.06
Basin 4	37,479	34.22	8.59	82.21
Basin 5	64,944	65.39	10.42	89.69
Total	118,537	71.13	--	--

The parameters from Table 1 served as inputs within the HydroCad stormwater modeling software. This computer-aided design tool is a hydrology and hydraulics software used to model stormwater runoff and design stormwater management systems. It was used to model the stormwater runoff volume, flow rates, and velocities within the existing stormwater structure. A comparative analysis was completed for each design alternative with further details in Appendix E.

3.0 Design Alternatives

3.1 Stormwater Best Management Practices

The GCSMM provides a description of BMPs that offer mitigation strategies and water quality treatment for stormwater runoff by reducing and treating stormwater runoff with natural processes on site. There are a total of 27 BMPs provided in the GCSMM. The applicability of each BMP was reviewed based on data from the site evaluation. All designs are meant to retain or treat the first 1.0-inch of rainfall, as recommended by the Manual. After project completion, the maintenance will be passed to the Gwinnett County Public School Building

Maintenance Department, therefore the burden of maintaining each BMP is also considered in the selection process. The spreadsheet matrix used to evaluate all BMPs can be seen in Appendix B.

3.2 Determination of Alternatives

The design alternatives proposed are based on BMPs that were identified to be best suited for the site and contribute to runoff reduction, and these are shown in Table 2. These BMPs accomplish the objectives of retaining the first inch of rainfall and reducing the load of total suspended solids by 80% and fit within location constraints.

Table 2: Identified Design Alternatives

ID	Description	BMP Type	Location	Basin Treated
A1	Bioretention basin inside the bus loop that treats runoff from paved surfaces	Bioretention Basin	Bus Loop	D5
A2	Replace sections of paved surfaces with permeable pavement	Permeable Pavement	Carpool Lot	D2 D3
A3	Replace islands within the parking lot with StormTree urban rain gardens	Bioretention Basin	Carpool Lot	D2 D3
A4	Dry Enhanced Swale	Dry Enhanced Swale	Entrance Drive	D4
Add-on	Decorative stormwater planters using roof runoff at school entrances	Downspout Disconnect Stormwater Planter	School Entrance	N/A

The Gwinnett County Stormwater Management standards were used to calculate the minimum volume requirements for the proposed runoff reduction and water quality improvement goals. The volumetric runoff coefficient (R_V) is a dimensionless coefficient relating the amount of runoff to the amount of precipitation received. The runoff reduction volume (RRv) is equal to the runoff generated on-site from 1.0 inches of rainfall. The water quality volume (WQv) is equal to the runoff generated on a site from 1.2 inches of rainfall, which also must be treated to the 80% TSS removal performance goal. The composite curve numbers (CN), area, percent impervious areas, and time of concentrations (Tc) for each drainage basin are summarized in Table 3. An iterative process was followed to generate an acceptable surface area and volume requirement to meet treatment requirements and size constraints for the site.

Table 3: Design Characteristics

Name	Site Area (SF)	% Impervious	R_V	RR_V (cf)	WQ_V (cf)
Basin 1	1,6631	81.41	0.78	1,085	1,302
Basin 2	61,784	86.75	0.83	4,277	5,132
Basin 3	40,122	79.42	0.76	2,557	3,069
Basin 4	37,479	34.22	0.36	1,118	1,342
Basin 5	64,944	65.39	0.64	3,341	4,010
Total	118,537	71.13	0.68	6,706	8,047

Furthermore, underdrains are systems of perforated pipe, designed to promote infiltration, filter pollutants, and connect a storage facility to an existing stormwater network. Underdrains may be open or upturned with a

90-degree elbow. Based on the Gwinnett DWR's preferences and past experiences, upturned underdrains were the preferred configuration to allow for greater runoff reduction potential through increased infiltration and treatment time. The local soils additionally have slow infiltration rates, so upturned underdrains are often required once a geotechnical analysis is completed during the design phase. Calculations have additionally found that this drain style provides a smaller footprint.

For every alternative, only upturned underdrains were evaluated to determine the surface area each BMP required to meet the water quality volume and runoff retention volume requirements. All detailed calculations can be found in Appendix C.

3.3 Alternative 1: Bioretention Basin

3.3.1 Design Overview

This alternative features the installation of a bioretention basin within the bus loop greenspace designed to capture 100% of runoff from Drainage Area 5, as shown in Figure 6. A bioretention basin uses a combination of specialty plantings and drainage systems to filter surface water runoff before it makes its way into the watershed. For this alternative, the minimum size of the bioretention basin required to satisfy the runoff reduction volume and water quality volume requirements is determined. It will utilize the inlet on the west side of Drainage Basin 5 to maximize collection of stormwater runoff from the basin. The existing greenspace within the bus loop is an oval shape, and the bioretention basin was sized to fit within and mirror the shape of this greenspace. The basin features will be placed to the north to avoid an existing fireline which runs underneath the greenspace, as highlighted in Figure 7. The design includes a border around the bioretention area, which allows for use, proper viewing, and safety concerns. Underdrains will be designed to tie into the manhole located at the west edge of Drainage Area 5.

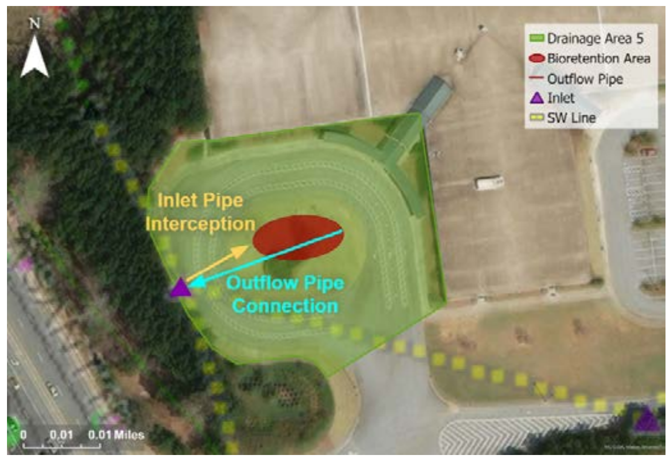

Figure 6: Drainage Basin treated by Alternative 1 (Esri, n.d; Gwinnett County GIS, 2020)

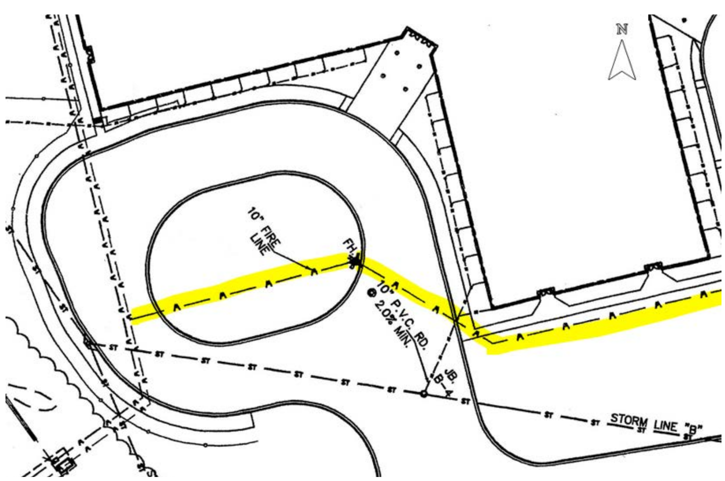

Figure 7: As-Built Drawing for Bus Loop with Fireline Highlighted (Eberly, 2002)

3.3.2 Underdrain System

An upturned underdrain configuration was evaluated to determine the area of the bioretention basin required to meet the water quality volume and runoff retention volume requirements. All detailed calculations can be found in Appendix C. As a result of the analysis, it was determined that the minimum surface area of the bioretention basin required was 2,970 SF. The bioretention basin is designed to be an oval that mimics the shape of the existing greenspace within the bus loop. The existing size of the greenspace is a 147’ x 108’ oval. It is originally designed to have an equal border on all sides, which was rounded to the nearest foot. However, due to site conditions, it is shifted north, so that the east and west sides are spaced equally, and the northern border is smaller than the southern. The actual size of the bioretention basin was calculated by solving for the maximum border length, which would lead to an area greater than or equal to the required basin area. Based on the oval design used, this corresponds with an actual area of 3,071 SF, with an upturned underdrain to satisfy these conditions.

Several site constraints were considered when designing the underdrain system. The first constraint is the fireline running through the bus loop. Plan views of the site show a fire hydrant located on the southeastern side of the bus loop grass area, with the corresponding fireline running underneath at a depth of about six feet underground. The bioretention basin placement is specially designed to avoid interacting with the fireline. The second constraint is that Drainage Area 5 is currently not graded to drain naturally to where the bioretention basin will be placed. Due to the 3% grade across the span of the bus loop, which includes a 7 ft elevation change over 200 ft, not all water which falls into the drainage basin will naturally travel to the BMP for treatment. An innovative pipe network is proposed to capture the entire drainage area, and proposed as the design basis. An alternative design based on the runoff that can be intercepted with the current site slopes and existing pipe networks is shown in Appendix D. The alternative drainage area for this design is shown in the appendix.

It was deemed unrealistic to regrade the entire bus loop to allow for all water to enter the BMP, due to high cost and water removal requirements. Instead, to maximize treatment, a novel approach for intercepting runoff from the inlet has been developed. The design is based on intercepting the vertical drop pipe at the existing inlet on the west side of the bus loop. The intercepted pipe would be re-routed to direct the runoff from the inlet back to the basin, where it will be treated before once again draining back into the stormwater line. A detailed design can be seen in Figure 8. The basin’s underdrains and overflow would tie into the manhole located at the west edge of the bus loop. The inlet will be provided with an overflow to the existing inlet drop, for occasions when rainfall outpaces the bioretention capacity, to prevent ponding on the bus loop.

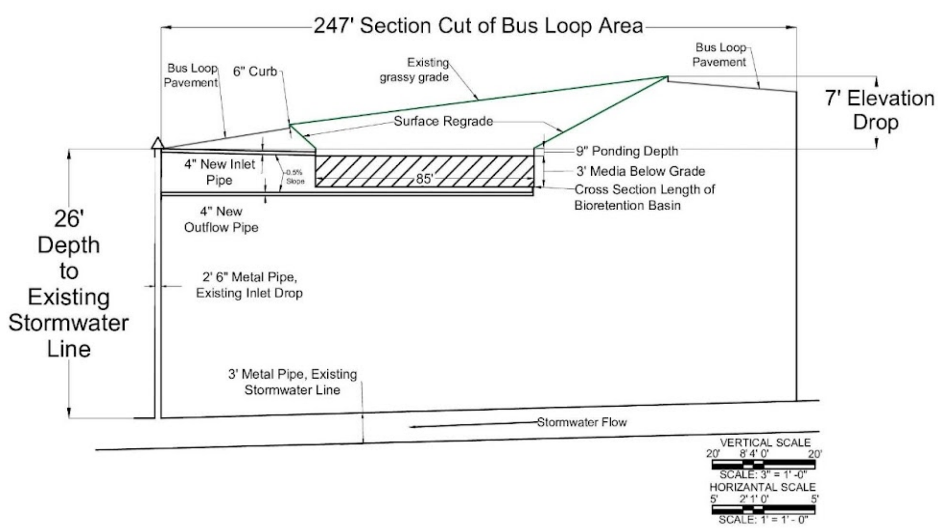

Figure 8: Pipe Network Concept (Created in AutoCAD)

3.3.3 Design Composition

The bioretention basin is designed to feature a 9-inch ponding depth, which provides temporary storage of the stormwater before it filters downward through the bioretention facility. There is additionally a 3 ft media below grade, which filters the water before entering the groundwater. The 3 ft depth consists of a 4” layer of mulch, a 22” layer of planting soil, a 4” layer of #8 gravel, and a 6” layer of #57 gravel as seen in Figure 9. There are additionally eight curb inlets which are designed to be inserted facing higher elevations around the existing curb to allow for further flow of water into the area.

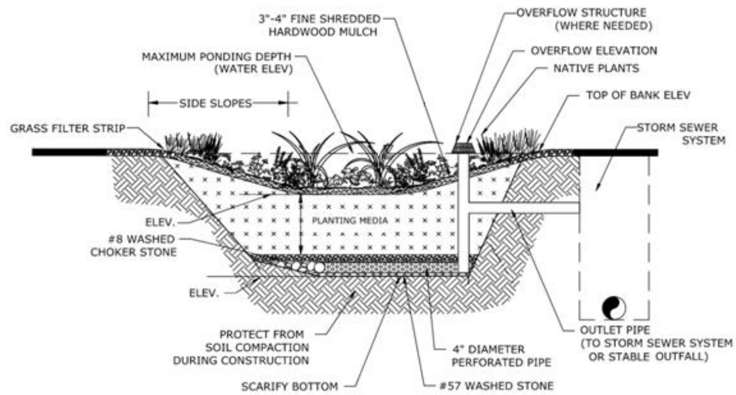

Figure 9: Bioretention Schematic with Underdrain (Gwinnett, 2020, Vol 2 p.166)

Figure 10 shows an aerial view of the bioretention basin design. The remaining area within the bus loop is designed to feature a 31’ grass border, which would act as a filtration strip for the incoming stormwater runoff. The south half of the loop serves as an educational area for classroom or club activities. A paver design will be implemented to allow for infiltration and public viewing areas, as well as potential areas for picnic tables. Duluth Middle School’s mascot is a wildcat, so a paw print symbol is incorporated into the stone pavers on the north side and the middle of the bioretention basin.

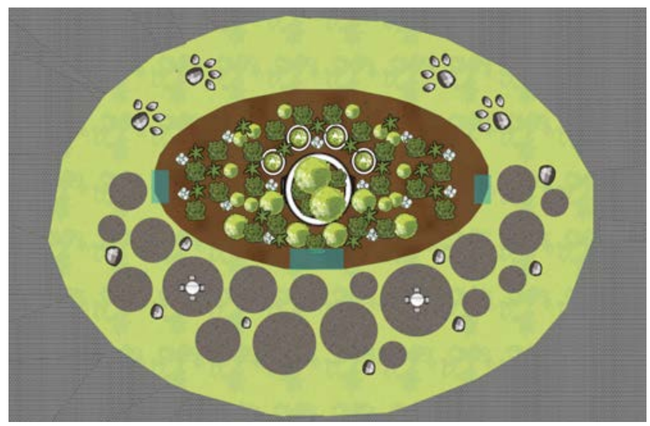

Figure 10: Concept Design Sketch for Bus Loop (Gardena, 2022)

3.4 Alternative 2: Pervious Pavement for Parking Lot

3.4.1 Design Overview

This alternative features the installation of pervious pavement intended for replacement within the parking lot designed to capture 100% of runoff from Drainage Basins 2 and 3, as shown in Figure 13. Pervious pavement is specialty pavement made of a porous material that enables stormwater to flow through it. For this alternative, the minimum amount of pervious pavement replacement required to satisfy the runoff reduction volume and water quality volume requirements is determined. The pervious pavement is designed to replace existing parking spaces within the carpool parking lot. It will continue to serve the functionality of parking spaces, as the pervious pavement used is rated to hold the same high stresses as typical, impervious pavement. The pervious parking spaces will be placed around current inlets within the drainage basin to ensure proper stormwater capture, as shown in Figure 11.

Figure 11: Alternative 2 Drainage Areas for Pervious Pavement (Esri, n.d.; Gwinnett County GIS, 2020)

3.4.2 Underdrain System

An upturned underdrain configuration was evaluated to determine the area of the pervious pavement installation required to meet the water quality volume and runoff retention volume requirements. It additionally has a unique gravel width requirement for proper infiltration. All detailed calculations can be found in Appendix C. As the result of analysis, it was determined that the minimum area of concrete required to be replaced was 11,000 SF.

The pervious pavement would replace existing parking spaces within the carpool parking lot as it receives less wear and tear. The pavement would be split into four 36’ x 70’ sections and one 36’ x 30’ section. The sections would replace 62 existing parking spaces within the carpool parking lot, as seen in Figure 11. The locations were selected closest to the existing stormwater inlets to ensure maximum stormwater runoff capture. The upturned underdrains of each section would be connected to the existing yard inlet within their respective drainage basin.

3.4.3 Design Composition

As seen in Figure 12, the pavement system would require 6” deep specialty pavement with a 2” layer of #8 gravel, and a 22” layer of #57 stone, which acts as a reservoir, holding rainwater while it slowly soaks into the ground.

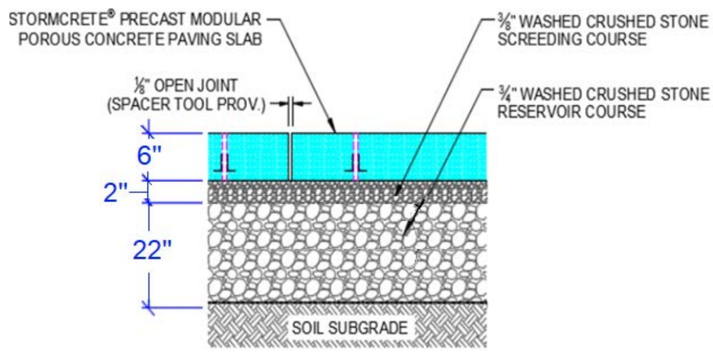

Figure 12: Stormcrete schematic (Stormcrete, 2021)

A specialty pervious pavement, Stormcrete, is designed to be used in this system. Stormcrete is a modular precast porous pavement stormwater system that is manufactured and cured in a controlled environment. As the sections arrive on site fully cured, they can be rapidly installed and immediately used afterward. There are permanent lifting points set into the surface of the slabs, which makes them removable and reusable (Stormcrete, 2021). Gwinnett County DWR recommended this product over typical, pour-in-place pervious pavement because of their cleanability, fast installation timeframe, and the additional challenges of meeting the required specifications with pour-in-place pervious pavement.

3.5 Alternative 3: Island StormTrees DrainGarden™

3.5.1 Design Overview

This alternative features the installation of an adapted StormTree DrainGarden™ model at the existing islands throughout the carpool lot within Drainage Areas 2 and 3, as shown in Figure 13. These implemented islands act very similarly to a bioretention basin and use a combination of specialty plantings and drainage systems to filter surface water runoff before it makes its way into the watershed. For this alternative, the minimum number of islands required to satisfy the runoff reduction volume and water quality volume requirements was determined. The calculations assumed that the islands could be modeled as bioretention basins. An average size for

Figure 13: Alternative 3 Drainage Areas and Suggested Placement (Esri, n.d.; Gwinnett County GIS, 2020)

each island was calculated to be 442 SF (13 ft x 34 ft) for the purpose of simplifying the calculations. There are 19 existing islands available to be converted into StormTree islands, and the proposed set of islands to convert are described in the following section.

3.5.2 Underdrain System

An upturned underdrain system was evaluated to determine the area of the StormTree islands required to meet the water quality volume and runoff retention volume requirements. As the result of the analysis, it was determined that the minimum surface area of the islands required to satisfy the water quality volume, and runoff retention volumes were 6,151 SF. As the average size of each parking lot island is 442 SF, this corresponds to approximately 14 islands required to be replaced. As seen in Figure 16, there are 19 islands within the drainage basins that are available to be converted into bioretention islands.

Due to concerns about clogging from soil runoff from the forest area on the east edge of the property, the five islands closest to the forest were not planned for replacement. The upturned underdrain of each island would connect to the underdrain of the island below it until the final underdrain outflows to the closest existing yard inlet in their respective drainage basins. As seen in Figure 13, the 8 islands being replaced in Drainage Basin 2 are all connected and routed to the yard inlet within the drainage basins, and the 6 islands being replaced in Drainage Basin 3 are routed to the gutter along the curb. The underdrain in each island is designed to connect to other islands, and all drain into the existing stormwater inlets in the parking lot.

3.5.3 Design Composition

The islands are each designed to feature a 9-inch ponding depth, which provides temporary storage of the stormwater before it filters downward through the bioretention facility. There is additionally a 3 ft media below grade, where water is filtered before entering the groundwater. The 3 ft depth consists of a 4" layer of mulch, a 22" layer of planting soil, a 4" layer of #8 gravel, and a 6" layer of #57 gravel as seen in Figure 14. There are additionally three curb inlets which are designed to be inserted in the existing curb in order to allow for further flow of water into the area.

Figure 14: StormTree Schematic (StormTree, n.d)

3.6 Alternative 4: Dry Enhanced Swale

3.6.1 Design Overview

This alternative features the implementation of dry-enhanced swale designed to capture 100% of runoff from Drainage Basin 4, as shown in Figure 15. A dry-enhanced swale is a surface channel that provides temporary storage for runoff, but that drains completely and remains dry between storm events. The swale provides downstream benefits by slowing the runoff, in turn allowing for greater retention time and drainage on site, as well as pollutant removal.

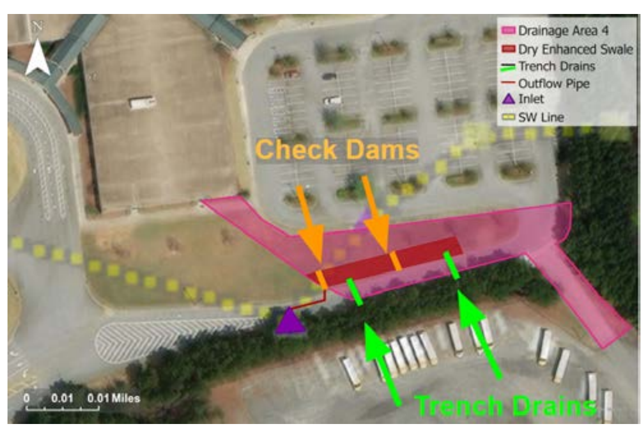

Figure 15: Alternative 4 Drainage Area for Swale (Esri, n.d.; Gwinnett County GIS, 2020)

3.6.2 Underdrain System

An upturned underdrain configuration was evaluated to determine the area of the dry enhanced swale needed to meet the water quality volume and runoff retention volume requirements. All detailed calculations can be found in Appendix C. This analysis determined that the required area for the bottom of the channel to satisfy the water quality and runoff reduction volumes, was 700 SF (100' x 7'). However, these dimensions did not meet the design requirements for erosive velocities of water moving down the channel. To account for the erosive velocity requirement, the swale is elongated such that the bottom area of the channel was increased to 1,240 SF (155' x 8'). For more details on the sizing adjustments, see Appendix C. The underdrain system ties in with an overflow weir and ties back into the existing stormwater line at the inlet in the center of the driveway.

3.6.3 Design Composition

The cross-section of the width of the channel can be seen in Figure 16. The swale is a trapezoidal channel that is 1.5' deep with a wall slope of 4:1. The bed of the swale is overlaid with 30" of engineered soils, and 6" of gravel, with the 4" underdrain running through the center of the gravel layer.

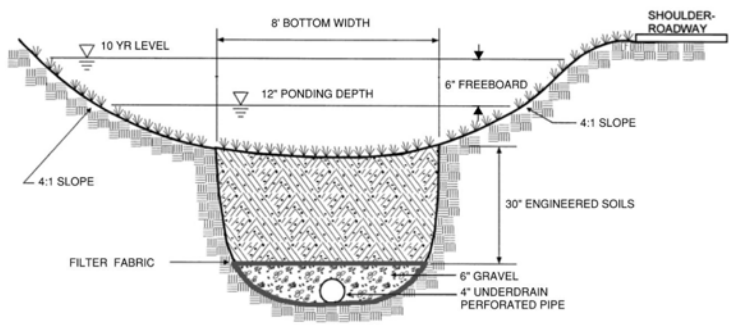

Figure 16: Width Cross-section of a Dry Enhanced Swale (Gwinnett, 2020, Vol 2 pg 222)

To account for the erosive velocities of the channel, the swale must be regarded to have a 1% slope, with a 1.5' drop in depth along the 155' length of the swale. Two check dams are added to the channel to slow the water velocity and increase the swale's retention time. These check dams are spaced 77.5' apart along the length of the swale. The cross-section along the length of the swale is shown in Figure 17.

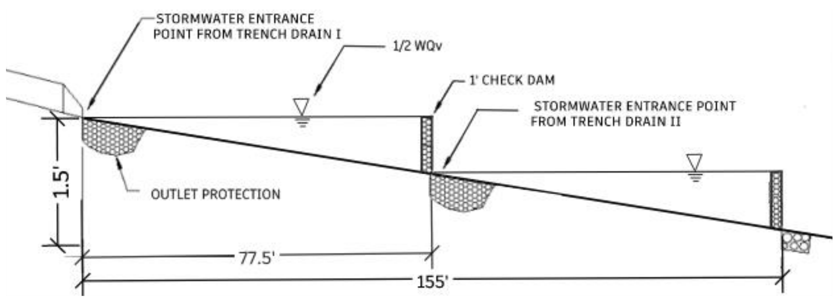

Figure 17: Length Cross-section of a Dry Enhanced Swale (Adapted from the Minnesota Stormwater Manual)

To redirect the runoff of the drainage area into the swale, two trench drains have been proposed. They would be placed perpendicular to the drive, and redirect runoff and drain into two outlets at the east end and the center of the swale, as shown in Figure 15. The trench drain outlets would be padded with riprap and extra vegetation. To accommodate the runoff from the entrance drive, each trench drain running 40' across the driveway would need to have a minimum depth of 5" below the grate. The design of the trench drains can be seen in the Appendix F.

3.7 Add-on Design Element Stormwater Gardens

The goal of installing stormwater planters is to meet the runoff reduction target, collecting the first 1" of rainfall from the roof. As previously stated, the runoff from the roof is currently moving from the downspouts to the stormwater lines, and into the site's existing retention basin.

The decorative stormwater planters would be fed by disconnecting existing downspouts from the stormwater pipes. This is a minor change that will not affect the structural integrity of the building, or intercept existing utility lines. Each planter is designed to handle the runoff from one downspout. Although this design features implementing the maximum possible number of planters, this design can be adjusted to place as many or as few planters as desired. The proposed location of the planters is shown in Figure 18.

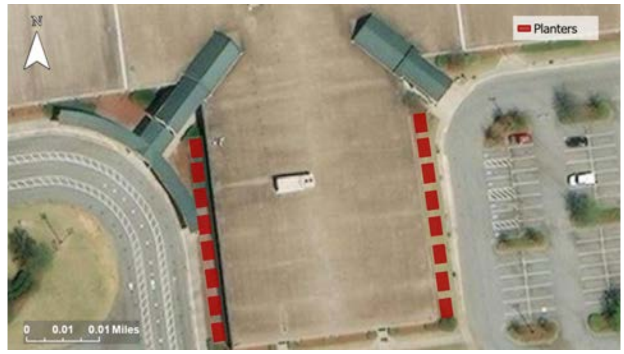

Figure 18: Add-on Design Element (Esri, n.d.)

Each downspout collects runoff from draining from about 1,500 SF of the roof. To treat the first inch of rainfall from this area of the roof, the stormwater planter needs to be 160 SF (16' x 10') and 4' deep. With the available site area, there is room for 16 total downspouts, with eight on both sides of the building, one connecting to each downspout as shown in Figure 18. However, as discussed later, only 14 will be installed. Figure 19 shows a schematic of a planter with water flowing from the downspout, through the growing medium and gravel, into an upturned underdrain. In the case of oversaturation in the soil, the water flows through directly to the overflow pipe. Both pipes lead to the outflow pipe, which connects back to the existing downspout. The downspout drains to the existing stormwater line. Within the 4 ft planter, there is a 1 ft ponding depth, and 3 ft of media, with 30" of engineered soils and 6" of gravel.

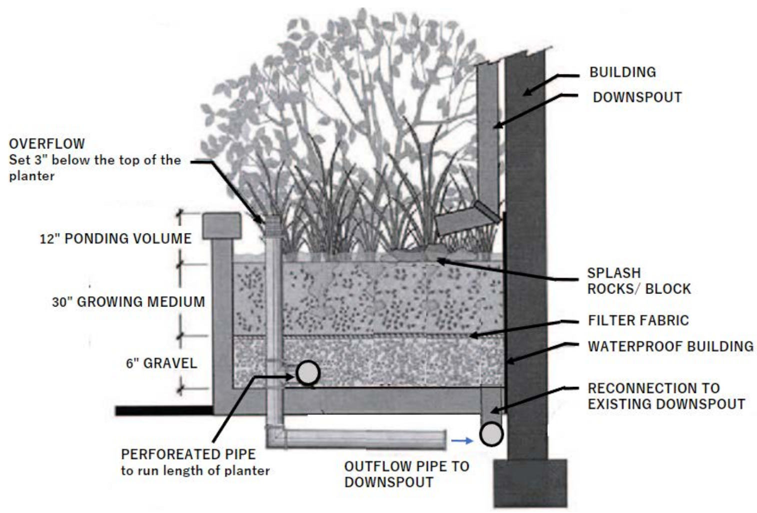

Figure 19: Planters Schematics (Gwinnett, 2020, Vol 2 pg 345)

4.0 Water Quality

4.1 Water Quality Volumes

Table 4 includes the calculated water quality volumes or the amount of stormwater runoff that needs to be captured and treated in order to remove a majority of stormwater pollutants, for each alternative.

Table 4: Water Quality Volumes per Alternative (cubic feet)

Alt 1: Bioretention Basin	Alt 2: Pervious Pavement	Alt 3: StormTree Islands	Alt 4: Dry Enhanced Swale	Add-on Option Per Planter	Add-on Option with 14 Planters
1,350	7,560	8,200	1,050	140	2,290

4.2 Site Pollutant Load

Using the EPA's 1999 "Preliminary Data Summary of Urban StormWater Best Management Practices" and assuming that the Duluth Middle School site is categorized as a commercial property, the median event mean concentrations per pollutant were calculated. The results are listed in Table 5. These values are to be used as the initial pollutant concentrations of the stormwater runoff before the runoff enters the BMPs.

Table 5: Mean Pollutant Concentrations for Commercial Properties

Pollutant	Mean Commercial Concentration (mg/L)
TSS	69
Metals (Lead, Copper, and Zinc)	0.359
Total Kjeldahl Nitrogen	1.179
Total Phosphorus	0.201

4.3 Total BMP Pollutant Load Reduction

Using the Gwinnett County Stormwater Management Manual, the following removal rates per each pollutant of interest are listed per BMP in Table 6.

Table 6: Pollutant Removal Rate per BMP

	Alt 1: Bioretention Basin	Alt 2: Pervious Pavement	Alt 3: StormTree Islands	Alt 4: Dry Enhanced Swale	Add-on Option: Planters
TSS	85%	80%	85%	80%	80%
Metals	75%	60%	75%	40%	0%
Nitrogen	25%	65%	25%	50%	60%
Phosphorus	60%	50%	60%	50%	60%

To determine the annual pollutant load for the site, the Simple Method equation from HydroCAD was used. Further detailed calculations can be found in Appendix C. The resulting annual gross TSS pollutant loads per each alternative are shown in light purple in Figure 20. The TSS pollutant removal rates shown above are used to calculate the adjusted TSS pollutant load per BMP as shown in dark purple in Figure 20.

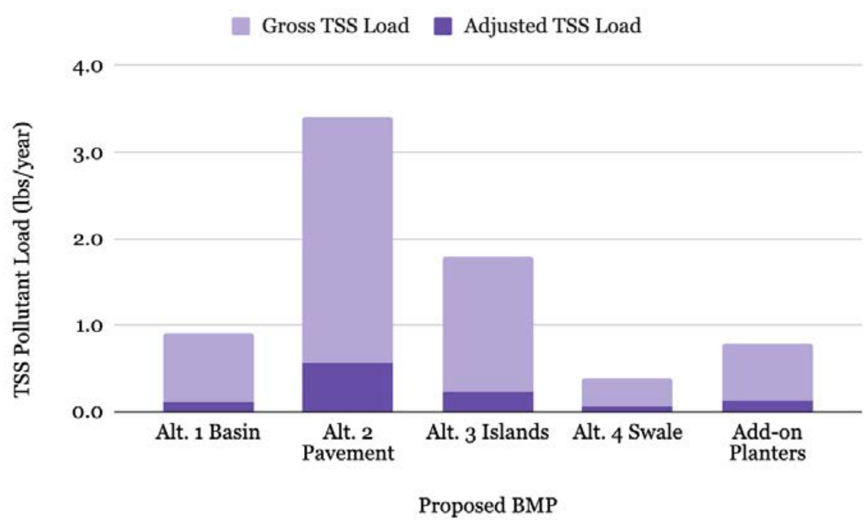

Figure 20: Annual TSS Pollutant Load Adjustment per BMP

5.0 Cost Comparison of Alternatives

5.1 Material and Installation

A cost estimation is provided by Harmonia for each alternative using unit costs retrieved from the 2017 RS Means database, and Gwinnett County's Annual Contract Bid Sheet. The opinion of probable cost covers the fees required for the materials and installation of each of the BMPs.

The unit costs retrieved from RS Means are based on 2017 costs and were updated to account for inflation. The U.S Bureau of Labor Statistics CPI Inflation stated that the inflation rate between January 2017 and February 2023 is 1.24 (Bureau, n.d.). All line item estimates from RS Means were multiplied by this value to adjust for inflation. All costs provided in the Gwinnett County Annual Contract Bid Sheets are from within the last year.

Table 7 represents a summary of the cost estimation for the four suggested design alternatives, and the add-on element. In Table 7, costs per unit were rounded up to the nearest hundred, and total costs per BMP approach were rounded up to the nearest thousand. The detailed cost breakdown for each alternative suggested can be found in Appendix G.

Table 7: Estimated Construction Cost Summary

BMP Type	Location	Basin Treated	Cost per Unit	Unit	Total Cost
Bioretention Basin	Bus Loop	B5	$166,700	1	$167,000
Permeable Pavement	Parking Lot	B2 B3	$475,200	1	$476,000
StormTree Islands	Parking Lot	B2 B3	$25,100	14	$352,000
Swale	Side Entrance	B4	$115,800	1	$116,000
Stormwater Planter	School Entrance	N/A	$13,800	14	$194,000

5.2 Operations and Maintenance

Maintenance is critical to ensuring that BMPs continue to work properly after they have been installed. Routine inspections enable any issues to be caught before they create larger problems. Common issues to check for during inspections include structural problems, excessive ponding, unhealthy or undesirable vegetation, erosion, clogging or deterioration of pipes, and poor infiltration rates. These issues will reduce the efficiency of runoff reduction and water quality treatment that each BMP can produce and cause additional issues. For example, poor drainage leads to ponding spaces where mosquitoes are able to breed. If the BMP is maintained to follow the suggested drainage times, there will be no habitat for breeding (Gwinnett County, 2020). General maintenance to avoid these issues include tasks such as removing built-up sediment, debris, or trash; removing debris from inflow and outflow structures; performing erosion or sediment control on portions where vegetation is missing; and replacing filter media as needed. During the first year that BMPs are installed, higher maintenance may be required to ensure the proper establishment of any vegetation in the practice. Table 8 provides a general breakdown of scheduled activities for BMPs (Stormcrete, 2021;StormTree, n.d.; Gwinnett County, 2020; Gwinnett County, 2023).

Table 8: General Maintenance Breakdown

Maintenance Activity	Alt 1: Bioretention Basin	Alt 2: Pervious Pavement	Alt 3: StormTree Islands	Alt 4: Dry Enhanced Swale	Add-on Option: Planters
Prune and weed plants	4x per growing season	X	4x per growing season	4x per growing season	Monthly
Dissipate flow when erosion is evident	4x per growing season	X	4x per growing season	4x per growing season	X
Remove trash and debris	4x per growing season	As needed	4x per growing season	4x per growing season	Monthly
Remove and replace dead or damaged plants	4x per growing season	X	4x per growing season	X	Annually
Mow grass height 4-6 inches	X	X	X	4x per growing season	X
Inspect for evidence of animal activity	4x per growing season	X	4x per growing season	4x per growing season	X
Observe infiltration rates after rain events to ensure there is no standing water after 24 hours	4x per growing season	X	4x per growing season	4x per growing season	2-3 years
Inspect for erosion, rills, or gullies, and repair	Semi-annually in spring and fall	Monthly	Semi-annually in spring and fall	Semi-annually in spring and fall	X
Trim planting material	As needed	X	As needed	As needed	Monthly
Inspect for snow accumulation	During winter months	X	During winter months	During winter months	During winter months
Ensure de-icing chemicals stay out of the BMP area	During winter months	X	During winter months	X	X
Test the planting soils for pH levels.	Annually	X	Annually	Annually	
Replace/repair inlets, outlets, scour protection or other structures as needed	Every 2-3 years	X	Every 2-3 years	Every 2-3 years	Annually
Implement maintenance plan to trim and divide perennials to prevent overcrowding and stress	Every 2-3 years	X	Every 2-3 years	Every 2-3 years	X
Check soil infiltration rates to ensure the soil is draining the water at a proper rate	Every 2-3 years	X	Every 2-3 years	Every 2-3 years	X

The bioretention basin, pervious pavement, and the StormTree islands require a moderate level of maintenance, and the dry-enhanced swale requires a low level of maintenance. To further reiterate, maintaining a BMP is crucial to keeping the BMP functioning properly. Additional research and analysis can be done on the implementation of an observation well or outflow weir to each BMP to allow for access to the outflow pipe and proper cleanout. Corresponding maintenance practices are important to consider when selecting BMPs, and ensuring all parties understand their respective responsibilities. Appendix H shows the annual maintenance costs for each BMP alternative and the add-on element based on their maintenance activities.

6.0 Recommended Alternatives

6.1 Alternative Evaluation

A decision matrix was used to assist in the evaluation decision making process, as seen in Table 9. For this matrix, the amount of potential runoff reduction, potential reduction amount of water quality, total estimated cost, maintenance burden, and visibility in terms of location for potential outreach were used as criterion. For each criterion, the BMP was assigned a score of 1 to 4, with 1 being the best score. Further descriptions of each criterion can be seen below. Each category was additionally assigned a weight factor as shown in the grey row. Runoff reduction, water quality and cost were ranked the most important, and ranked equally, because they were the key limitations of the chosen designs. Runoff reduction and water quality were ranked equally, because in the case that runoff reduction design requirements could not be met, the water quality requirements would be used. No additional budget specifications were given, therefore cost was ranked as equal in importance to the effectiveness. Maintenance was considered for design sustainability and visibility was an added benefit that coincided with the client's values. The final score is found by adding the products of the weight factors and category scores for each BMP. For the purpose of this matrix, the BMP assigned the lowest weighted score is the preferred choice.

Table 9: Alternative Ranking Method Using Weighted Sores

	Runoff Reduction	Water Quality	Cost	Maintenance	Visibility	Weighted Score	Overall Rank
Weight	**0.25**	**0.25**	**0.25**	**0.15**	**0.10**	**-**	**-**
1. Bioretention Basin	1	1	2	2	1	1.4	1
2. Pervious Pavement	1	2	4	2	4	2.45	4
3. Island StormTrees	1	1	3	2	2	1.75	3
4. Dry Enhanced Swale	1	2	1	1	3	1.45	2

For the runoff reduction criteria, every alternative was designed to meet 100% of the runoff reduction design criteria, so every alternative is ranked as one.

The ranking of the water quality is based on its ability to remove total TSS. The bioretention basin and the island StormTrees both remove 85% of TSS, therefore they are ranked as one. The pervious pavement and dry-enhanced swale remove 80% of TSS, therefore they are ranked as two.

For costs, a score of one denotes costs between \$0- \$120K, two denotes between \$120K- 240K, three denotes between \$240K- \$360K, and four denotes \$360K- \$480K. The ranking is based on the estimated costs shown in Table 7. From least to most expensive, the alternatives are the dry enhanced swale, bioretention basin, island StormTrees, and pervious pavement.

The maintenance burden is ranked to be minimized, on a scale of three to one, where one is the most desirable ranked alternative. The GCSWM lists the expected maintenance of each BMP as having either a high, medium, or low burden. The bioretention basin, pervious pavement, and island StormTrees all have medium maintenance burdens, thus they are ranked at two. The dry-enhanced swale has a low maintenance burden, therefore it is ranked one.

The visibility variable was added to account for Gwinnett DWR's desire to have the GSIs accessible to the public. The bioretention basin is placed in the middle of the bus loop, giving it increased foot traffic from students during school dropoff and pickup times, therefore it is ranked one. The Island StormTrees and dry-enhanced swale are visible to those using the carpool lot, thus they are ranked two, and three respectively. The pervious pavement is not meant to be noticeably different from the existing lot, thus it is ranked four.

6.2 Chosen Alternatives

A two-tiered budget was provided by Gwinnett DWR and was used in conjunction with the rankings above to determine final site approach. The DWR budget options included:

Option 1: A budget of $500K will be followed to select the maximum number of alternatives based on the ranking, as well as the Add-on option.

Option 2: A budget of $650K will be considered if this provides additional opportunities for BMP selection beyond the previous option provided.

Based on these rankings and the budget implemented, Harmonia recommends Alternative 1, the Bioretention Basin, and Alternative 4, the Dry Enhanced Swale be implemented at the site along with 14 of the stormwater planters as an add-on feature. The resulting Opinion of Probable Cost (OPC) to implement these three components is $477,000. The two alternatives and the add-on element are economically viable and under the budget listed by Option 1. Attempting to add another BMP exceeds the secondary budget option provided by Gwinnett DWR, therefore Option 2 is not a viable proposal.

6.3 Possible Project Expansion Opportunities

The alternatives suggested are within the given budget set by Gwinnett DWR. To expand the number of BMPs implemented, Gwinnett DWR can apply to get funding for further implementation of the project. Harmonia recommends applying for the Georgia Environmental Protection Division (GAEPD) 319(h) grant. Georgia's Nonpoint Source Implementation Grant awards funds to projects that address nonpoint sources of pollution by identifying and implementing activities best suited to address those sources resulting in measurable water quality improvements to impaired waters throughout the state. The grant requires a cost-share ratio of 60% Federal dollars (maximum) and 40% non-federal match (minimum) toward the total project cost. The maximum Federal award to any individual project is $400,000 with no minimum Federal award amount (Georgia EPD, 2023).

7.0 Public Education and Outreach

The implementation of GSI at Duluth Middle School provides a unique opportunity to foster environmental stewardship through outreach and public education. On a typical school day, Duluth Middle School is visited by students, teachers, and parents; thus, the construction of visible and accessible GSI on-site allows for the education of various demographics in the Duluth community on stormwater technologies. Through accessible signage, class activities, and club involvement, the aim of these educational opportunities is for students to develop a

Figure 21: Educational Sign Locations (Esri, n.d.)

sense of responsibility towards their natural environment. By making GSI visible and accessible, the students at Duluth Middle are able to realize that they too can play an active role in watershed protection and generate a positive impact in their community.

The placement of signs at the front of Duluth Middle School allows for a quick and easy way to educate students, teachers, and parents as they walk into and around the school. These signs will highlight the overall importance of protecting local watersheds, discuss the benefits of capturing and cleaning stormwater, and describe how each BMP works. Proposed locations for the plaques that optimize visibility are shown in Figure 22. The signs can also include a QR code to the Gwinnett County DWR website for information or videos specific to that BMP, as seen in Figure 22.

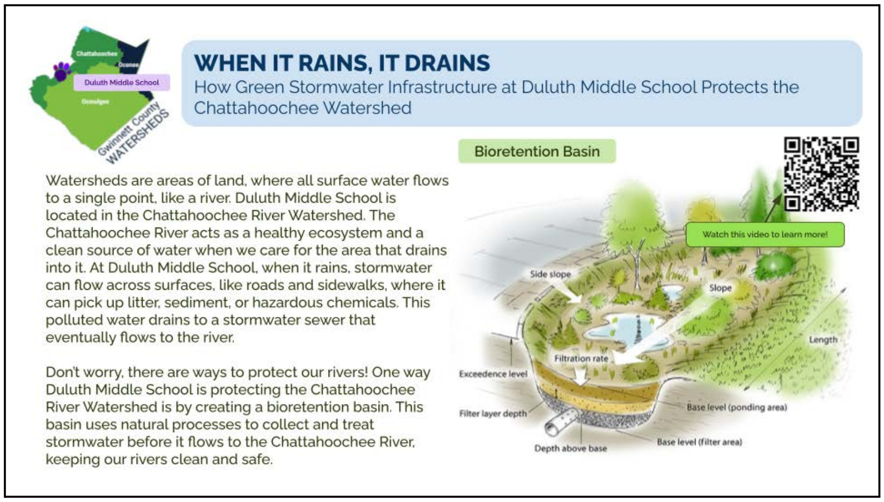

Figure 22: Educational Sign Example (Adapted from Innovyze)

The construction of BMPs on-site also allows for interactive classroom activities and lessons that connect the existing curriculum to GSI. Table 10 displays how aspects of on-site GSI could be easily integrated into Gwinnett County's Academic Knowledge and Standards (AKS) for middle school curriculums.

Table 10: Relation of GSI and Environmental Stewardship in Gwinnett County AKS

AKS Standard	Rationale
6th Grade	
Obtain, evaluate, and communicate information to recognize the significant role of water in Earth processes.	Learn the importance of clean water as a natural resource necessary to human and ecosystem health.
Obtain, evaluate, and communicate information about the uses and conservation of various natural resources and how they impact Earth.	Understand the importance of watershed protection and its impact on ecosystem services.
7th Grade	
Obtain, evaluate, and communicate information to examine the interdependence of organisms with one another and their environments.	Learn about how water quality affects the health of an ecosystem and its organisms in the food web.
8th Grade	
Obtain, evaluate, and communicate information about the phenomena of gravity, electricity, and magnetism as major forces acting in nature	Understand how the implemented GSI utilizes natural forces, like gravity and infiltration, to reduce runoff and pollutants.
Analyze and interpret data to identify patterns in the relationships between speed and distance and velocity and acceleration	Calculate the velocity of the stormwater as it moves to and through a GSI practice.

Offering a seminar and supplementary material to interested teachers at Duluth Middle School may be the best way to distribute the information in Table 10. Teachers may implement the information into their curriculums and provide the information to their students as they see fit.

Outside of the school's curriculum, Duluth Middle School students could interact with the BMPs through extracurricular clubs. Existing clubs at Duluth Middle School that may relate to environmentalism and engineering include the *STEM GEMS Club*, *Student Council*, J*unior BETA Club*, and the *Environmental & Gardening Club*. The clubs could provide extra immersion through GSI research projects, field sampling opportunities, and rain garden volunteer hours.

Additional outreach events that could provide further exposure to the newly implemented BMPs include offering tours during Parent-Teacher conferences and Back to School Open Houses. Tours would discuss the importance of watershed quality, the benefits of capturing stormwater runoff, and explanations of each BMP. Through the signage available on-site, visitors could also use the QR codes for additional information. The tours could be given by Gwinnett County DWR volunteers or older students who have been involved with the project in the past. These are only a few examples of how the GSI at Duluth Middle can be used to teach students and community members about watershed protection.

8.0 Conclusion

The recommended green stormwater infrastructure for Duluth Middle School includes three design elements. The first two design alternatives are a bioretention basin in the bus loop and the dry enhanced swale at the greenspace of the entrance drive. Both alternatives were limited by the ability to regrade the site and required innovation to redirect 100% of the runoff from their respective drainage basins. Per the Gwinnett DWR's request, both design alternatives utilized upturned underdrains. The last design is an add-on element, of stormwater planters fed by disconnected downspouts. The roof runoff is considered to have a low pollutant load, as the majority of pollution in the area is from car traffic, and the planters are included to increase the visual and educational impact of this stormwater improvement project.

The bioretention basin is an 85' by 46' oval that captures runoff from Drainage Basin 5. The bus loop could not be regraded so to maximize capture and treatment, Harmonia Engineering proposed a novel collection system. The system intercepts the vertical drop pipe at the existing inlet on the west side of the bus loop. The intercepted pipe would be re-routed to direct the runoff from the inlet back to the basin, before once again draining back into the stormwater line. The remaining area within the bus loop is designed to feature a 31' grass border, which would act as a filtration strip for the incoming stormwater runoff. The south half of the loop serves as an educational area for classroom or club activities. A permeable paver design will be implemented in the south half to allow for infiltration and public viewing as well as to relocate the existing picnic tables.

The dry enhanced swale is a 155' x 20' channel that captures runoff from Drainage Basin 4 and is placed in the green space parallel to the entrance drive. It also includes two check dams and an underdrain running along the center. The underdrain and outflow pipe drain back into the existing stormwater inlet at the center of the entrance drive. As with the bus loop, the water naturally flows to the existing outlet and is too steep to regrade. To capture the runoff, trench drains are placed perpendicular to the entrance drive, and emptied into the swale.

Duluth Middle School was selected as a candidate for a stormwater improvement project by Gwinnett County in part for its potential as a GSI demonstration project. The implementation of GSI at Duluth Middle School provides a unique opportunity to foster environmental stewardship through outreach and public education because this site is visited by students, teachers, and families on a daily basis. By making GSI visible and accessible, the students at Duluth Middle can realize that they too can play an active role in watershed protection and generate a positive impact on their community. Through accessible signage, class activities, and club involvement, the aim of these educational and extracurricular opportunities is for students to develop a sense of responsibility towards their natural environment that will go beyond their time at Duluth Middle School.

Sustainability is an important factor to consider in the design and construction of an infrastructure project for a community. The installation of GSI at Duluth Middle School is an economically feasible solution to improving the quality of stormwater entering the Chattahoochee River watershed. The bioretention basin and stormwater planters are designed to reduce the total suspended solids loading and thus reduce metal content, improving human and environmental health and reducing further treatment costs. Thus, the installation has the opportunity to improve the economic viability, environmental protection, and social well-being of Duluth, in turn addressing all three aspects of sustainability.

The next steps of this project would involve a multi-stage review performed by licensed professionals. A geotechnical assessment should be completed in order to confirm the assumed soil types and measure respective infiltration rates. Permitting applications also need to be submitted and approved in order to begin project construction. Finally, professional engineers need to review the designs and calculations included in this report.

9.0 References

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Appendices

Appendix A: Pre-Developed Site Conditions

Figure A-1 displays the major soil types in the site area. More details about each soil type can additionally be seen in Table A-1.

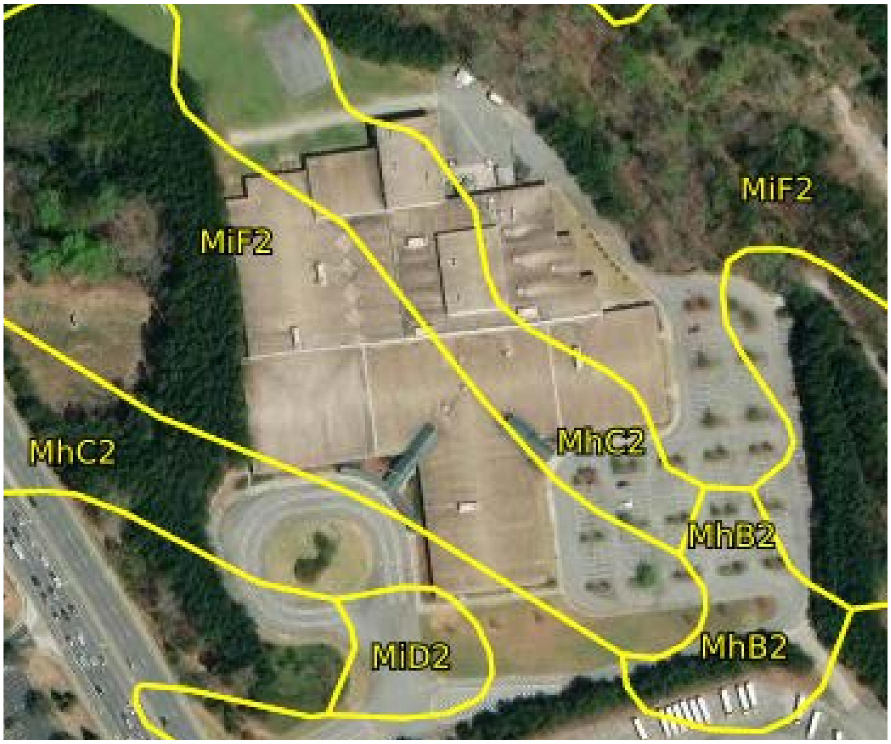


Figure A-1: Site Soil Types (Gwinnett County GIS, 2020)

Table A-1: Pre-Developed Site Soil Types

Soil Type	Description	Available Water Storage (cm)	Infiltration Rate (in/hr)	Drainage Class
MhB2	Madison gravelly sandy loam, 2 to 6 percent slopes, eroded	14.55	0.31	Well drained
MiF2	Madison sandy clay loam, 15 to 45 percent slopes, eroded	15.00	0.08	Well drained
MhC2	Madison gravelly sandy loam, 6 to 10 percent slopes, eroded	14.55	0.45	Well drained
MiD2	Madison sandy clay loam, 10 to 15 percent slopes, moderately eroded	11.09	0.12	Well drained

Appendix B: Preliminary BMP Identification

Table B-1: Preliminary BMP Identification

BMP	Runoff Reduction	80% TSS Removal?	LID/GI?	Construction Cost	Maintenance Burden		Possible Option
Bioretention Basin	Yes	Yes	Yes	High	Med		Yes
Bioslopes	Yes	Yes	Yes	Med	Med		Maybe
Downspout Disconnects	Yes	Yes	Yes	Low	Low		No
Dry Detention Basins	No	No	No	Low	Low		No
Dry Wells	Yes	Yes	Yes	Med	Med		No
Enhanced Dry Swales	Yes	Yes	Yes	Med	Low		Yes
Enhanced Wet Swales	No	Yes	Yes	Med	Low		No
Grass Channels	Minimal	No	Yes	Low	Low		Maybe
Gravity (oil-grit) separators	No	No	No	High	High		No
Green Roofs	Yes	Yes	Yes	High	Low		No
Infiltration Trenches	Yes	Varies	Yes	High	High		No
Multipurpose Detention Basins	No	Yes	No	Low	Low		No
Organic Filters	No	Yes	Yes	High	High		No
Permeable Paver Systems	Yes	Yes	Yes	High	High		Maybe
Pervious Concrete	Yes	Yes	Yes	High	High		Maybe
Porous Asphalt	Yes	Yes	Yes	Med	Med		Yes
Rainwater Harvesting	No	Varies	Yes	Med	High		No
Regenerative Stormwater Conveyance	No	Yes	Yes	High	Med		Maybe
Sand Filters	No	Yes	Yes	High	High		No
Site Reforestation/Revegetation	No	N/A	Yes	Med	Low		No
Soil Restoration	No	N/A	Yes	Med	Low		No
Stormwater Planters/ Tree Boxes	Yes	Yes	Yes	High	Med		Yes
Stormwater Ponds	No	Yes	No	Low	Low		No
Stormwater Wetlands	No	Yes	Yes	Med	Med		No
Submerged Gravel Wetlands	No	Yes	No	High	High		No
Underground Detention	No	No	No	High	Med		No
Vegetated Filter Strips	Yes	No	Yes	Low	Low		Maybe

Appendix C: Calculations

Calculated Variables	Units	Basin 1	Basin 2	Basin 3	Basin 4	Basin 5	Total
Site Area	sqft	16631.00	61784.00	40122.00	37479.00	62797.00	118537.00
% Impervious	%	0.8141	0.8675	0.7942	0.3422	0.6539	0.70
Rv	-	0.78	0.83	0.76	0.36	0.64	0.68
RRv	cf	1085	4277	2557	1118	3341	6706
WQv	cf	1302	5132	3069	1342	4010	8047

Water Quality Peak Flow Calculations	Units	Basin 1	Basin 2	Basin 3	Basin 4	Basin 5	
P	inch	1.20	1.20	1.20	1.20	1.20	
P_2	inch	3.71	3.71	3.71	3.71	3.71	
CN	-	93.54	94.82	93.06	82.21	89.69	
S	inch	0.69	0.55	0.75	2.16	1.15	
I_a (table 3.1.5-3)	inch	0.14	0.11	0.15	0.43	0.23	
Q (eq 3.1.5)	inch	0.64	0.73	0.61	0.20	0.44	
S_grass	ft/ft	0.080	0.200	0.004	0.036	0.015	
S_Concrete	ft/ft	0.053	0.022	0.010	0.022	0.025	
n_grass	-	0.15	0.15	0.15	0.15	0.15	
n_Concrete	-	0.01	0.01	0.01	0.01	0.01	
V_grass (eq 3.1.9)	ft/s	4.56	7.21	1.02	3.05	1.99	
V_Concrete (eq 3.1.10)	ft/s	4.70	2.99	2.06	3.03	3.23	
L_Grass	ft	188.56	298.14	42.16	125.99	82.37	
L_Concrete	ft	81.00	340.00	270.00	425.00	310.00	
t_c (eq 3.1.7) total	min	6.19	6.51	11.52	10.22	10.79	
I_a/P (Figure 4-1,)	-	0.12	0.09	0.12	0.36	0.19	
q_u (Figure 3.1.5-6)	csm/in	950.00	1000.00	775.00	800.00	825.00	
F_p	-	1.00	1.00	1.00	1.00	1.00	
Q_p (eq	cfs	0.36	1.61	0.69	0.22	0.83	

Figure C-1: Printout from Preliminary Design Calculations using TR-55

Below are sample calculations following the design procedure and criteria from the GCSMM, completed for all four alternatives, as well as the add-on option. All calculations below are designed for an upturned underdrain.

Alternative 1: Bioretention Basin

Bioretention Basin Site Flow/Runoff Reduction:

$$R_v = 0.05 + 0.009 * I = 0.05 + 0.009 * \frac{41,062\ SF}{62,797\ SF} = 0.638$$

$$RR_v = \frac{(A * R_v * P)}{12} = \frac{(62,797\ SF * 0.638 * 1\ in)}{12\ in/ft} = 3,341\ cf$$

$$VP_{min} = \frac{RR_v}{\%RR} = \frac{3341\ cf}{0.75} = 4,455\ cf$$

$$PV = A_{pond} * d_{pond} = 3,071\ SF * 0.75\ ft = 2,303\ cf$$

$$VES = A_{pond} * N_{media} * d_{media} = 3,071\ SF * 0.25 * 3\ ft = 2,303\ cf$$

$$VP = PV + VES\ (N) = 2,303\ cf + 2,303\ cf = 4,606\ cf$$

$$A_f = \frac{VP_{min}}{d_p + N * d_r} = \frac{4,455\ cf}{0.75\ ft + 0.25 * 3\ ft} = 2,970\ SF$$

Water Quality

$$WQ_v = \frac{1.2 * R_v * A}{12} = \frac{1.2\ in * 0.638 * 62797\ SF}{12\ in/ft} = 4,010\ cf$$

$$A_f = \frac{WQ_v * (d_r)}{k(n_r + d_r) * t_r} = \frac{4,010\ cf * 3\ ft}{1\ ft/day\ (1\ ft + 3\ ft) * 1\ day} = 3,008\ cf$$

Drain Time Bioretention Basin

$$Surface\ area\ of\ pond\ (A_{pond})\ =\ \pi * r_1 * r_2 = \pi * 42.5\,ft\ * 23\,ft\ = 3,071\,SF$$

$$Circumference\ of\ Pond\ (C_{pond})\ =\ 2\pi\sqrt{\frac{r_1^2+r_2^2}{2}}\ =\ 2\pi\sqrt{\frac{(42.5\,ft)^2+(23\,ft)^2}{2}}\ =\ 215\,ft$$

$$Soil\ Surface\ Area\ =\ A_{pond}\ +C_{pond} \times D_{Media} = 3,071\,SF\ +\ 215\,ft\ *\ 3\,ft\ = 2,715\,SF$$

$$Ponding\ Volume\ (PV)\ =\ A_{pond}\ \times\ D_{pond} =\ 3,071\,SF\ *\ 0.75\,ft\ = 2,303\,cf$$

$$Soil\ Volume\ (V_{Soil})\ =\ A_{pond} \times D_{Media} = 3,071\,SF\ * 3\,ft\ = 9,213\,cf$$

$$Total\ Volume\ (TV)\ =\ PV\ + V_{Soil} \times N\ =\ 2,303\,cf\ +\ 9,213\,cf\ *\ 0.25\ =\ 4,606\,cf$$

$$Drain\ time\ Ponding\ Volume\ (t_{PV})\ = \frac{Ponding\ Volume}{Soil\ Surface\ Area \times Infiltration\ Rate} = \frac{2,303\ cf}{2,715\ SF\ *0.042\ ft/hr} = 14.8\,hr$$

$$Drain\ time\ Total\ Volume\ (t_{TV})\ = \frac{Total\ \ Volume}{Soil\ Surface\ Area \times Infiltration\ Rate} = \frac{4,606\ cf}{2,715\ SF\ *0.042\ ft/hr} = 29.5\,hr$$

Exact Size Calculation

The Bioretention Basin is designed to be an oval which mimics the shape of the existing greenspace within the bus loop. The existing size of the greenspace is an 147' x 108' oval. It is designed to have an equal border on all sides, which was intended to be an integer value. In order to calculate the minimum size of the bioretention basin which is greater than or equal to the required area as closely as possible, the following equation was used, where b represents the length of the border.

$$2970\,SF\ \ = \frac{\pi}{4} * (147\,ft\ -\ 2b)\ *\ (108\,ft\ \ -\ \ 2b)$$

Solving this equation leads to the maximum border length to be 31 ft, and corresponds to a 85 ft by 46 ft oval.

Alternative 2: Pervious Pavement

Site Flow/Runoff Reduction

$$R_v = 0.05\ +\ 0.009 * I\ = 0.05\ +\ 0.009 * \frac{85,461\ SF - 11,000\ SF\ *0.65}{101,906\ SF} = 0.742$$

$$RR_v = \frac{(A*R_v*P)}{12}\ =\ \frac{(101,906\ SF * 0.742 * 1\ in)}{12\ in/ft} = 6,298\,cf$$

$$VP_{min} = \frac{RR_v}{\%RR}\ = \frac{6,298\ cf}{0.75} = 8,397\,cf$$

$$VP\ =\ VBL\ *\ N\ = \frac{24\ in * 11,000\ SF}{12\ in/ft} *\ 0.40\ = 8,800\,cf$$

Water Quality

$$WQ_v = \frac{1.2*R_v*A}{12}\ = \frac{1.2\ in * 0.742 *101,906\ \ SF}{12\ in/ft} = 7,558\,cf$$

$$A_f = \frac{WQ_v*(d_{pc}+d_{ri})}{(k_{pc}*d_{pc}*t_{pc})+(k_{r1}*d_{r1}*t_{ri1})} = \frac{7,558\ cf * (\ 2\ \ ft + 0.5\ ft)}{(0.66\ ft/hr\ \ * 0.5\ ft * 0.72\ hr) + (1\ ft/day * 2\ ft * 1\ day)} = 8,274\,SF$$

Drainage Time

$$Drain\ time\ (t)\ = \frac{Storm\ Runoff\ Volume}{Surface\ Area \times Subsoil\ Design\ Permeability\ Rate} = \frac{6,298\ cf}{(11,000\ SF * 0.66\ ft/hr)} = 0.86\,hr$$

Alternative 3: StormTree Islands

Site Flow/Runoff Reduction:

$$R_v = 0.05 + 0.009 * I = 0.05 + 0.009 * \frac{85{,}461\ SF}{101{,}906\ SF} = 0.805$$

$$RR_v = \frac{(A*R_v*P)}{12} = \frac{(101{,}906\ SF * 0.805 * 1\ in)}{12\ in/ft} = 6{,}834\ cf$$

$$VP_{min} = \frac{RR_v}{\%RR} = \frac{6{,}834\ cf}{0.75} = 9112\ cf$$

$$PV = A_{pond} * d_{pond} = 442\ SF * 0.75\ ft = 332\ cf$$

$$VES = A_{pond} * N_{media} * d_{media} = 442\ SF * 0.25 * 3\ ft = 332\ cf$$

$$VP = PV + VES\ (N) = 332\ cf + 332\ cf = 664\ cf$$

As VP is smaller than VP_{min}, we have to increase the total number of islands.

$$N_{islands} = \frac{VP_{min}}{Vp} = \frac{9{,}112\ cf}{664\ cf\ per\ island} = 14\ islands\ required$$

14 islands are required to handle to total flow

$$A_f = \frac{VP_{min}}{d_p + N*d_r} = \frac{9{,}112\ cf}{0.75\ ft + 0.25 * 3\ ft} = 6{,}075\ SF$$

Water Quality

$$WQ_v = \frac{1.2*R_v*A}{12} = \frac{1.2 * 0.805 * 101{,}906\ SF}{12} = 8{,}201\ cf$$

$$A_{fq} = \frac{WQ_v*(d_r)}{k(n_r + d_r*t_r)} = \frac{8{,}201\ cf * 0.83\ ft}{1\ ft/day\ (1\ ft + 3\ ft) * 1\ day} = 6{,}151\ SF$$

$$N_{islands} = \frac{A_{fg}}{A} = \frac{6{,}151\ SF}{440\ SF\ per\ island} = 14\ islands\ required$$

As there are 14 islands required to satisfy both the runoff reduction and the water quality requirement, 14 islands will be used.

Drain Time Bioretention Basin

$$Surface\ area\ of\ pond\ (A_{pond}) = L * W = 13\ ft * 34\ ft = 442\ SF$$

$$Circumference\ of\ Pond\ (C_{pond}) = 2(L + W) = 2(13\ ft + 34\ ft) = 94\ ft$$

$$Soil\ Surface\ Area = A_{pond} + C_{pond} \times D_{Media} = 442\ SF + 94\ ft * 3\ ft = 724\ SF$$

$$Ponding\ Volume\ (PV) = A_{pond} \times D_{pond} = 442\ SF * 0.75\ ft = 332\ cf$$

$$Soil\ Volume\ (V_{Soil}) = A_{pond} \times D_{Media} = 442\ SF * 3\ ft = 1326\ cf$$

$$Total\ Volume\ (TV) = PV + V_{Soil} \times N = 332\ cf + 1326\ cf * 0.25 = 664\ cf$$

$$Drain\ time\ Ponding\ Volume\ (t_{PV}) = \frac{Ponding\ Volume}{Soil\ Surface\ Area \times Infiltration\ Rate} = \frac{332\ cf}{724\ SF * 0.042\ ft/hr} = 11.0\ hr$$

$$Drain\ time\ Total\ Volume\ (t_{TV}) = \frac{Total\ Volume}{Soil\ Surface\ Area \times Infiltration\ Rate} = \frac{664\ cf}{724\ SF * 0.042\ ft/hr} = 21.8\ hr$$

Alternative 4: Dry Enhanced Swale

Site Flow/Runoff Reduction

$R_v = 0.05 + 0.009 * I = 0.05 + 0.009 * \frac{10{,}114.32\ SF}{28{,}690.74\ SF} = 0.367$

$RR_v = \frac{(A*R_v*P)}{12} = \frac{(21{,}350\ SF * 0.491 * 1\ in)}{12\ in/ft} = 878.12\ cf$

Minimum Treatment Volume

$VP_{min} = \frac{RR_v}{\%RR} = \frac{874.21\ cf}{0.75} = 1{,}170.83\ cf$

Swale Dimensions for a Trapezoidal Channel

$A_{pond\ cross\ section} = 0.5 * (Bottom\ Width + Top\ Width) * Depth = 0.5\,(20' + 8') * 1' = 14\ SF$

$PV = A_{pond\ cross\ section} * l_{pond} = 14\ SF * 155\ ft = 2170\ cf$

$VES = A_{soil} * d_{soil} = 1{,}240\ SF * 3\ ft = 3{,}720\ cf$

Required Storage Volume

$VP = PV + N_{media} * VES = 2{,}170\ cf + 0.25 * 3{,}720\ cf = 3{,}100\ cf$

$VP > VP_{min}$

Therefore the swale meets runoff reduction requirements.

$A_{min} = \frac{VP_{min}}{d_p + N*d_r} = \frac{1{,}170.83\ cf}{1\ ft + 0.25 * 3\ ft} = 700\ SF$

Water Quality

$WQ_v = \frac{1.2*R_v*A}{12} = \frac{1.2 * 0.367*21{,}350\ SF}{12\ in/ft} = 1{,}053.74\ cf$

The storage volume provided by the swale (VP) is greater than the water quality volume (WQ), therefore the proposed sizing satisfies the water quality design criteria.

Adjustments for Erosive Velocities

The maximum erosive velocity of a straight channel lined with a grass mixture and a 0-5% slope is 4 ft/s (Table 5.4-3, GCSWM). For straight channels, the mannings number is $n = 0.035$. This calculation assumes that the channel is at its maximum ponding height.

$Channel\ Velocity = \frac{1.49}{n} * R^{2/3}S^{1/2} = \frac{1.49}{0.035} * 0.01^{1/2} = 3.34\ ft/s$

$S = \frac{Channel\ Drop}{Total\ Channel\ Length} = \frac{1.5'}{155'} = 0.01$

$Wetted\ Perimeter = Bottom\ Width + 2\sqrt{(\frac{Top\ Width - Bottom\ Width}{2})^2 + Height^2}$

$= 8 + 2\sqrt{(\frac{20\ ft - 8\ ft}{2})^2 + 1\ ft^2} = 20.16\ ft$

$R = Ponding\ Cross\ Section/Wetter\ Perimeter = \frac{14\ SF}{20.16\ ft} = 0.69\ ft$

Dimensions for $Channel\ Bottom\ Area = 155'\ x\ 8'$

This dimension was found by adjusting swale dimensions until the channel velocity dropped below the maximum erosive velocity. The dimensions were originally tested with the area required to meet runoff reduction volumes (700 SF (100’ x 7’)). These dimensions did not meet erosive velocity requirements, therefore dimensions were adjusted. Thus, the swale dimensions are determined by the erosive velocities, rather than the runoff reduction or water quality volumes.

Number of Check Dams

Check dams are designed to be the height of the ponding volume: $h_{check\ dam} = 1\,ft$. This assumption, and the calculations for the check dams, are from the Minnesota Stormwater Manual.

$$Distance\ Between\ Check\ Dams = \frac{h_{check\ dam}}{S} = \frac{1\,ft}{0.01} = 103.4\,ft$$

$$Number\ of\ Check\ Dams = \frac{Length\ of\ Swale}{Distance\ Between\ Check\ Dams} = \frac{155\,ft}{103.4\,ft} = 1.49$$

Therefore 2 check dams are required.

Swale Drainage Time

$$Ponding\ Drainage\ Time = \frac{Ponding\ Volume}{Surface\ Area * Infiltration\ Rate} = \frac{2170\,cf}{3{,}255\,SF * (0.042\,ft/hr)} = 15.8\,hr$$

$$Surface\ Area_{ponding} = Wetted\ Perimeter * Length = 21\,ft * 155\,ft = 3{,}255\,SF$$

$$Total\ Drainage\ Time = \frac{Total\ Volume}{Surface\ Area * Infiltration\ Rate} = \frac{3{,}100\,cf}{13{,}225\,SF * (0.042\,ft/hr)} = 22.67\,hr$$

Add-on: Planters

Site Flow/Runoff Reduction

$$R_v = 0.05 + 0.009 * I = 0.05 + 0.009 * \frac{1500\ SF}{1500\,SF} = 0.95$$

$$RR_v = \frac{(A*R_v*P)}{12} = \frac{(1{,}500\,SF * 0.95 * 1\,in)}{12} = 118.75\,cf$$

Minimum Treatment Volume

$$VP_{min} = \frac{RR_v}{\%RR} = \frac{118.75\,cf}{0.75} = 158.33\ cf$$

Planter Dimensions

$$PV = A_{pond} * d_{pond} = 160\,SF * 0.75\,ft = 120\,cf$$

$$VES = A_{soil} * d_{soil} = 160\,SF * 3\,ft = 480\,cf$$

Pretreatment Volume

$$VP = PV + N_{media} * VES = 120\,cf + 0.25 * 480\,cf = 240\,cf$$

$$VP > VP_{min}$$

Therefore the planters can be sized using the requirements for runoff reduction requirements.

$$A_{min} = \frac{VP_{min}}{d_p + N*d_r} = \frac{237.50\,cf}{0.75\,ft + 0.25 * 3\,ft} = 159\,SF$$

Water Quality

$$WQ_v = \frac{1.2\,in * R_v * A}{12} = \frac{1.2*0.95*1{,}500\,SF}{12} = 142.\ 5\,cf$$

$$A_f = \frac{WQ_v*(d_r)}{k(n_r + d_r)*t_r} = \frac{142.5\,cf * 3\,ft}{1\,ft/day\,(1\,ft + 3\,ft)*1\,day} = 114\,cf$$

The treatment volume provided is greater than the water quality volume, and the area sized for runoff is greater than the water quality design criteria. Therefore the water quality design criteria are satisfied.

Drainage Time

$$Ponding\ Drainage\ Time = \frac{Ponding\ Volume}{Surface\ Area * Infiltration\ Rate} = \frac{120\,cf}{160\,SF * (0.042\,ft/hr)} = 17.9\,hr$$

$$Total\ Drainage\ Time = \frac{Total\ Volume}{Surface\ Area * Infiltration\ Rate} = \frac{240\,cf}{160\,SF * (0.042\,ft/hr)} = 35.7\,hr$$

Water Quality Calculations

$$L = (P)\,(R_v)\,(C)\,(A)\,(0.20)^*$$

Where:

- L = Load of a pollutant in pounds per year
- P = Rainfall depth per year (inches)
- R_v = Runoff coefficient, which expresses the fraction of rainfall which is converted into runoff = 0.05 + 0.009(I)
- I = Site imperviousness (i.e., I = 75 if site is 75% impervious)
- C = Flow-weighted mean concentration of the pollutant (total phosphorus) in urban runoff (mg/l) = 0.30 mg/l**
- A = Area of the development site (acres)

*0.20 is a regional constant and unit conversion factor

** The C factor can be customized if good local water quality data exist or if an adjustment in the 0.30 mg/l term is needed.

Figure C-2: Simplified Pollutant Loading Calculation (HydroCAD Software Solutions LLC, 2022)

Appendix D: Alternative 1 without Water Redirection Methods

Design a bioretention basin within the bus loop to capture 100% of runoff from an adjusted Drainage Area 5, as shown in Figure D-1. For this alternative, the minimum size of the bioretention basin required to satisfy the runoff reduction volume and water quality volume requirements is determined. Underdrains will be designed to tie into the manhole located at the west edge of Drainage Area 5. This design omits the specialty pipe system described in the report above and is intended to provide the background for the design with minimal change required for the alternative.

Figure D-1: Alternative 1 No Change Drainage Area

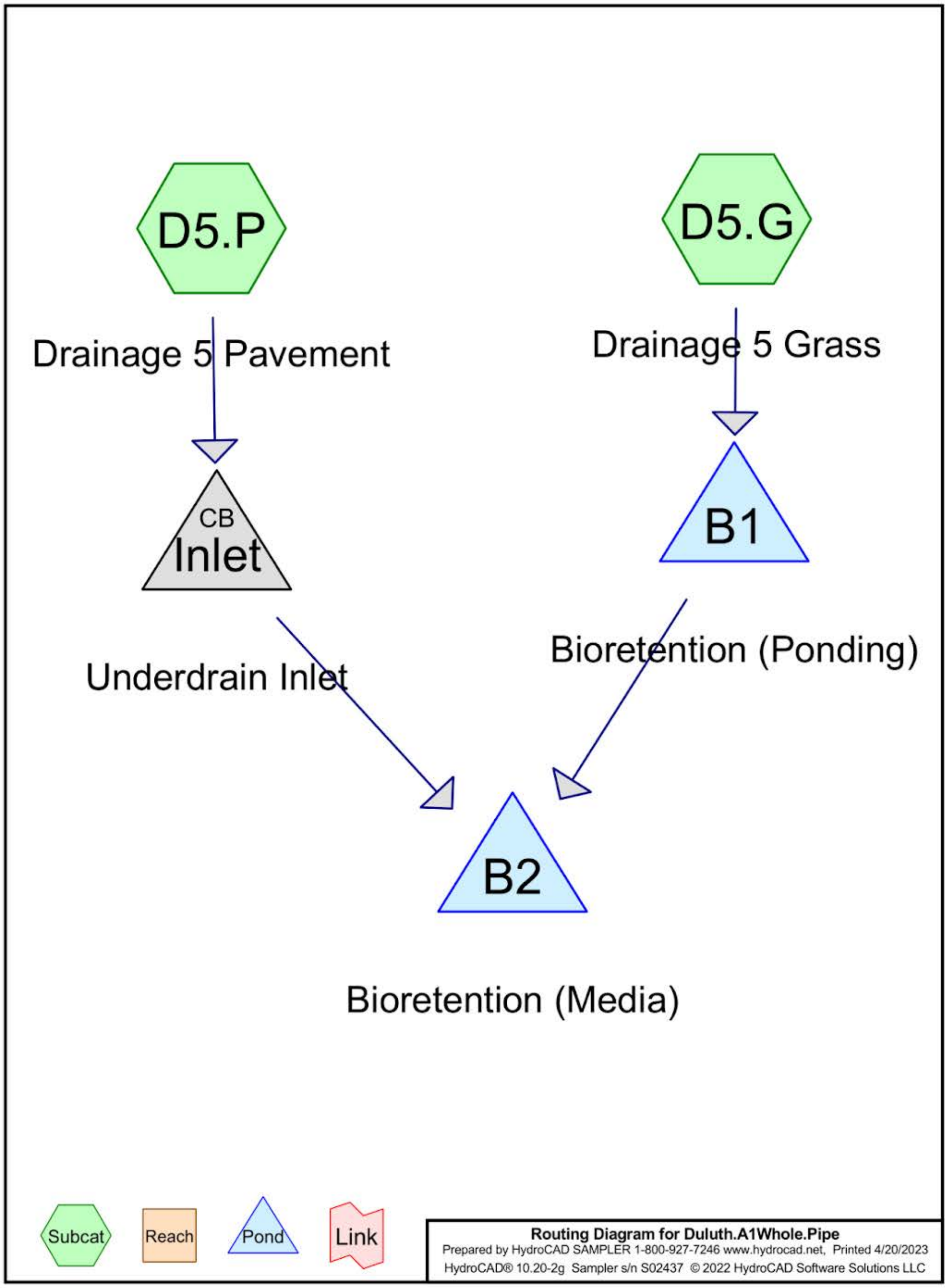
Two underdrain configurations were evaluated to determine the area of the bioretention basin required to meet the water quality volume and runoff retention volume requirements.

As the result of the analysis, it was determined that the minimum surface area of the bioretention basin required to satisfy the water quality volume, and runoff retention volumes is 1,016 SF for the upturned. Based on the half-circle design implemented, this corresponds with an area of 1060 SF used to satisfy these conditions.

It is also designed to feature a 9-inch ponding depth, which provides temporary storage of the stormwater before it filters downward through the bioretention facility. There is additionally a 3 ft media below grade, where water is filtered before entering the groundwater. The 3 ft depth consists of a 4” layer of mulch, a 22” layer of planting soil, a 4” layer of #8 gravel, and a 6” layer of #57 gravel.

Appendix E: Hydrocad Analysis of Design Alternatives

Alternative 1: Bioretention Basin



Area Listing (all nodes)

Area (acres)	CN	Description (subcatchment-numbers)
0.071	74	>75% Grass cover, Good, HSG C (D5.G)
0.311	98	Paved parking, HSG C (D5.P)
0.382	**94**	**TOTAL AREA**

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Soil Listing (all nodes)

Area (acres)	Soil Group	Subcatchment Numbers
0.000	HSG A	
0.000	HSG B	
0.382	HSG C	D5.G, D5.P
0.000	HSG D	
0.000	Other	
0.382		**TOTAL AREA**

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Ground Covers (all nodes)

HSG-A (acres)	HSG-B (acres)	HSG-C (acres)	HSG-D (acres)	Other (acres)	Total (acres)	Ground Cover	Subcatchment Numbers
0.000	0.000	0.071	0.000	0.000	0.071	>75% Grass cover, Good	D5.G
0.000	0.000	0.311	0.000	0.000	0.311	Paved parking	D5.P
0.000	**0.000**	**0.382**	**0.000**	**0.000**	**0.382**	**TOTAL AREA**	

Pipe Listing (all nodes)

Line#	Node Number	In-Invert (feet)	Out-Invert (feet)	Length (feet)	Slope (ft/ft)	n	Width (inches)	Diam/Height (inches)	Inside-Fill (inches)
1	B2	1,035.25	1,031.95	165.0	0.0200	0.010	0.0	4.0	0.0
2	Inlet	1,034.25	1,033.25	80.0	0.0125	0.010	0.0	4.0	0.0

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Time span=4.00-24.00 hrs, dt=0.05 hrs, 401 points
Runoff by SCS TR-20 method, UH=SCS, Weighted-CN
Reach routing by Dyn-Stor-Ind method - Pond routing by Dyn-Stor-Ind method

Subcatchment D5.G: Drainage 5 Grass Runoff Area=3,092 sf 0.00% Impervious Runoff Depth>0.02"
Flow Length=82' Slope=0.0150 '/' Tc=8.7 min CN=74 Runoff=0.00 cfs 0.000 af

Subcatchment D5.P: Drainage 5 Runoff Area=13,539 sf 100.00% Impervious Runoff Depth>0.79"
Flow Length=310' Slope=0.0250 '/' Tc=2.1 min CN=98 Runoff=0.43 cfs 0.020 af

Pond B1: Bioretention (Ponding) Peak Elev=1,038.25' Storage=0 cf Inflow=0.00 cfs 0.000 af
Discarded=0.00 cfs 0.000 af Primary=0.00 cfs 0.000 af Outflow=0.00 cfs 0.000 af

Pond B2: Bioretention (Media) Peak Elev=1,035.78' Storage=192 cf Inflow=0.43 cfs 0.021 af
Discarded=0.00 cfs 0.000 af Primary=0.25 cfs 0.020 af Outflow=0.25 cfs 0.020 af

Pond Inlet: Underdrain Inlet Peak Elev=1,038.56' Inflow=0.43 cfs 0.020 af
4.0" Round Culvert n=0.010 L=80.0' S=0.0125 '/' Outflow=0.43 cfs 0.020 af

Total Runoff Area = 0.382 ac Runoff Volume = 0.021 af Average Runoff Depth = 0.65"
18.59% Pervious = 0.071 ac 81.41% Impervious = 0.311 ac

Summary for Subcatchment D5.G: Drainage 5 Grass

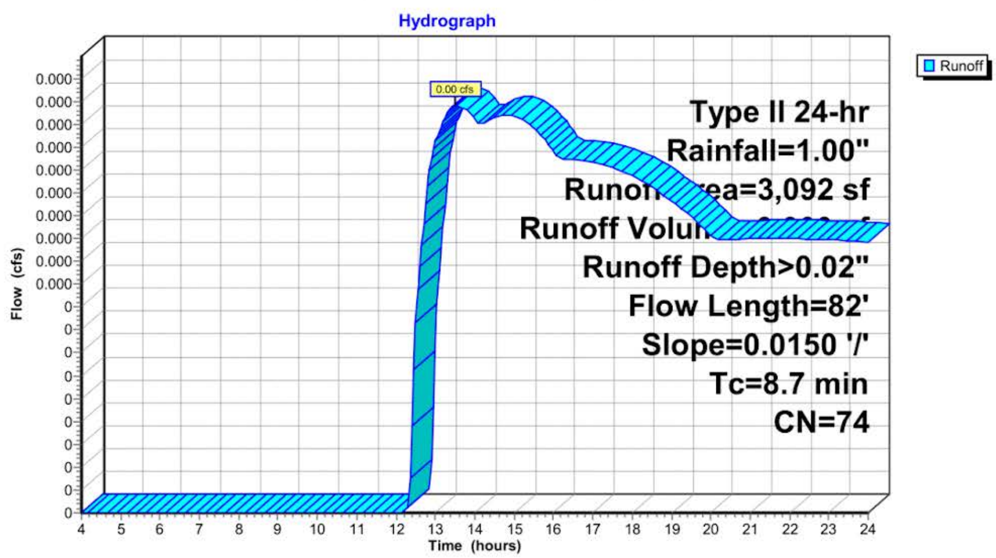
Runoff = 0.00 cfs @ 13.49 hrs, Volume= 0.000 af, Depth> 0.02"
Routed to Pond B1 : Bioretention (Ponding)

Runoff by SCS TR-20 method, UH=SCS, Weighted-CN, Time Span= 4.00-24.00 hrs, dt= 0.05 hrs
Type II 24-hr Rainfall=1.00"

Area (sf)	CN	Description
3,092	74	>75% Grass cover, Good, HSG C
3,092		100.00% Pervious Area

Tc (min)	Length (feet)	Slope (ft/ft)	Velocity (ft/sec)	Capacity (cfs)	Description
8.7	82	0.0150	0.16		**Sheet Flow, Grass** Grass: Short n= 0.150 P2= 3.71"

Subcatchment D5.G: Drainage 5 Grass



Summary for Subcatchment D5.P: Drainage 5 Pavement

[49] Hint: Tc<2dt may require smaller dt

Runoff = 0.43 cfs @ 11.92 hrs, Volume= 0.020 af, Depth> 0.79"
Routed to Pond Inlet : Underdrain Inlet

Runoff by SCS TR-20 method, UH=SCS, Weighted-CN, Time Span= 4.00-24.00 hrs, dt= 0.05 hrs
Type II 24-hr Rainfall=1.00"

Area (sf)	CN	Description
13,539	98	Paved parking, HSG C
13,539		100.00% Impervious Area

Tc (min)	Length (feet)	Slope (ft/ft)	Velocity (ft/sec)	Capacity (cfs)	Description
1.0	100	0.0250	1.62		**Sheet Flow, Pavement** Smooth surfaces n= 0.011 P2= 3.71"
1.1	210	0.0250	3.21		**Shallow Concentrated Flow, Pavement** Paved Kv= 20.3 fps
2.1	310	Total			

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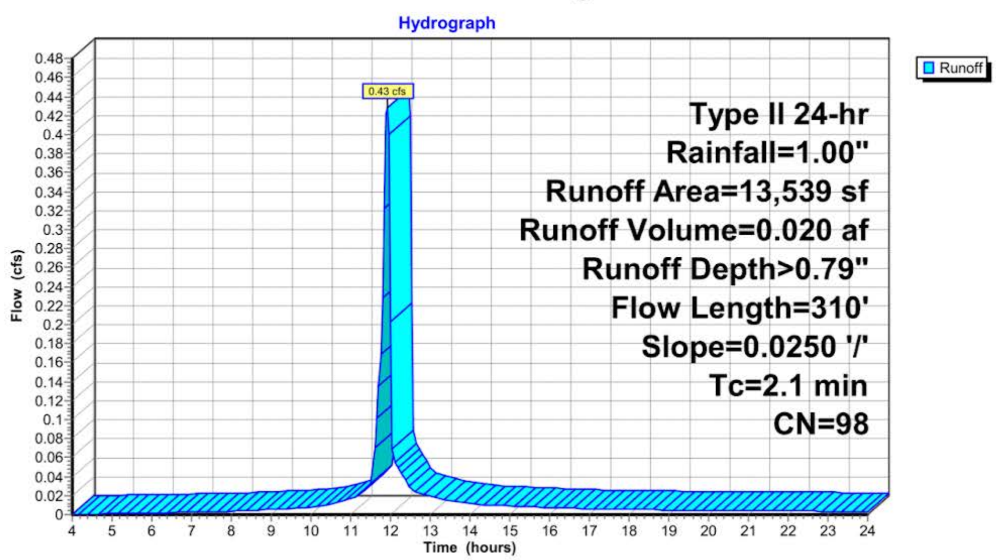
Subcatchment D5.P: Drainage 5 Pavement



Summary for Pond B1: Bioretention (Ponding)

Inflow Area = 0.071 ac, 0.00% Impervious, Inflow Depth > 0.02"
Inflow = 0.00 cfs @ 13.49 hrs, Volume= 0.000 af
Outflow = 0.00 cfs @ 13.49 hrs, Volume= 0.000 af, Atten= 0%, Lag= 0.0 min
Discarded = 0.00 cfs @ 4.00 hrs, Volume= 0.000 af
Primary = 0.00 cfs @ 13.49 hrs, Volume= 0.000 af
Routed to Pond B2 : Bioretention (Media)

Routing by Dyn-Stor-Ind method, Time Span= 4.00-24.00 hrs, dt= 0.05 hrs
Peak Elev= 1,038.25' @ 4.00 hrs Surf.Area= 1,039 sf Storage= 0 cf

Plug-Flow detention time= (not calculated: outflow precedes inflow)
Center-of-Mass det. time= 0.0 min (1,068.6 - 1,068.6)

Volume	Invert	Avail.Storage	Storage Description
#1	1,038.25'	787 cf	**Custom Stage Data (Prismatic)** Listed below (Recalc)

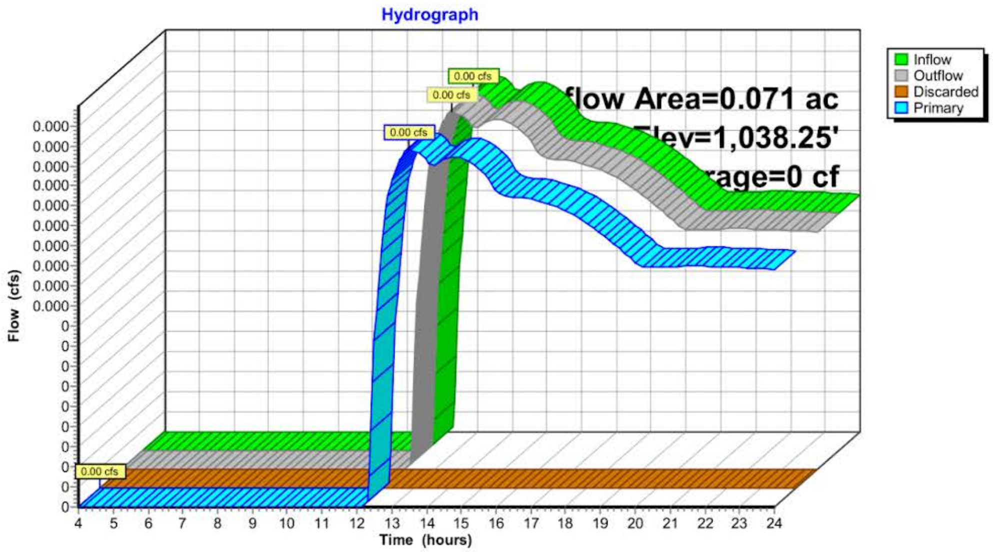
Elevation (feet)	Surf.Area (sq-ft)	Inc.Store (cubic-feet)	Cum.Store (cubic-feet)
1,038.25	1,039	0	0
1,039.00	1,060	787	787

Device	Routing	Invert	Outlet Devices
#1	Primary	1,038.25'	**0.05 cfs Exfiltration at all elevations**
#2	Discarded	1,038.90'	**4.0" Vert. Orifice/Grate** C= 0.600 Limited to weir flow at low heads

Discarded OutFlow Max=0.00 cfs @ 4.00 hrs HW=1,038.25' (Free Discharge)
└─**2=Orifice/Grate** (Controls 0.00 cfs)

Primary OutFlow Max=0.00 cfs @ 13.49 hrs HW=1,038.25' TW=1,035.33' (Dynamic Tailwater)
└─**1=Exfiltration** (Passes 0.00 cfs of 0.05 cfs potential flow)

Pond B1: Bioretention (Ponding)



Summary for Pond B2: Bioretention (Media)

Inflow Area = 0.382 ac, 81.41% Impervious, Inflow Depth > 0.65"
Inflow = 0.43 cfs @ 11.92 hrs, Volume= 0.021 af
Outflow = 0.25 cfs @ 11.99 hrs, Volume= 0.020 af, Atten= 41%, Lag= 4.5 min
Discarded = 0.00 cfs @ 11.99 hrs, Volume= 0.000 af
Primary = 0.25 cfs @ 11.99 hrs, Volume= 0.020 af

Routing by Dyn-Stor-Ind method, Time Span= 4.00-24.00 hrs, dt= 0.05 hrs
Peak Elev= 1,035.78' @ 11.99 hrs Surf.Area= 918 sf Storage= 192 cf

Plug-Flow detention time= 27.1 min calculated for 0.020 af (98% of inflow)
Center-of-Mass det. time= 17.8 min (800.7 - 782.9)

Volume	Invert	Avail.Storage	Storage Description
#1	1,035.25'	1,159 cf	**Custom Stage Data (Prismatic)** Listed below (Recalc) 2,897 cf Overall x 40.0% Voids

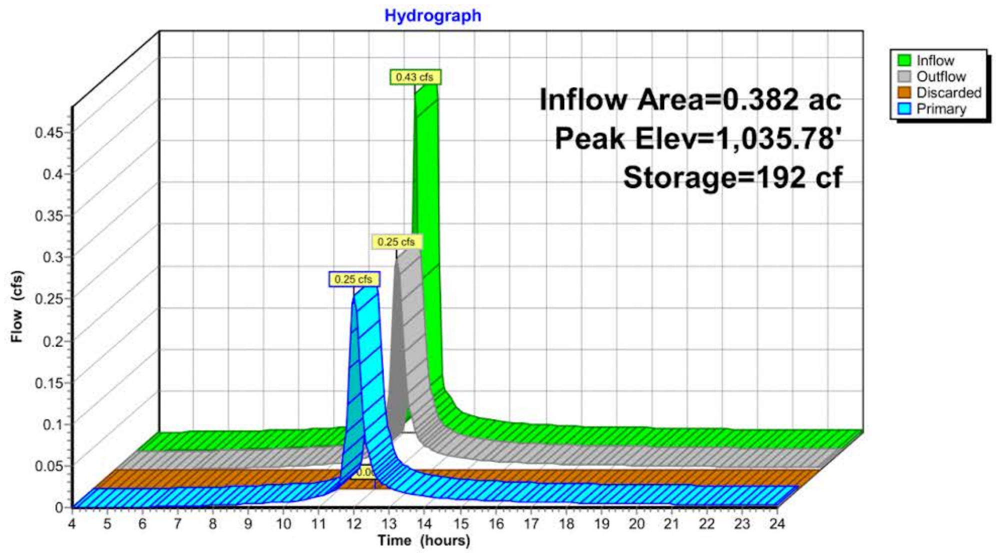
Elevation (feet)	Surf.Area (sq-ft)	Inc.Store (cubic-feet)	Cum.Store (cubic-feet)
1,035.25	892	0	0
1,038.25	1,039	2,897	2,897

Device	Routing	Invert	Outlet Devices
#1	Primary	1,035.25'	**4.0" Round Culvert** L= 165.0' CMP, square edge headwall, Ke= 0.500 Inlet / Outlet Invert= 1,035.25' / 1,031.95' S= 0.0200 '/' Cc= 0.900 n= 0.010 PVC, smooth interior, Flow Area= 0.09 sf
#2	Discarded	1,035.25'	**0.005 in/hr Exfiltration X 0.10 over Surface area**

Discarded OutFlow Max=0.00 cfs @ 11.99 hrs HW=1,035.78' (Free Discharge)
↑—**2=Exfiltration** (Exfiltration Controls 0.00 cfs)

Primary OutFlow Max=0.25 cfs @ 11.99 hrs HW=1,035.78' (Free Discharge)
↑—**1=Culvert** (Inlet Controls 0.25 cfs @ 2.88 fps)

Pond B2: Bioretention (Media)



Summary for Pond Inlet: Underdrain Inlet

[57] Hint: Peaked at 1,038.56' (Flood elevation advised)

Inflow Area = 0.311 ac,100.00% Impervious, Inflow Depth > 0.79"
Inflow = 0.43 cfs @ 11.92 hrs, Volume= 0.020 af
Outflow = 0.43 cfs @ 11.92 hrs, Volume= 0.020 af, Atten= 0%, Lag= 0.0 min
Primary = 0.43 cfs @ 11.92 hrs, Volume= 0.020 af
Routed to Pond B2 : Bioretention (Media)

Routing by Dyn-Stor-Ind method, Time Span= 4.00-24.00 hrs, dt= 0.05 hrs
Peak Elev= 1,038.56' @ 11.92 hrs

Device	Routing	Invert	Outlet Devices
#1	Primary	1,034.25'	**4.0" Round Culvert** L= 80.0' CMP, square edge headwall, Ke= 0.500 Inlet / Outlet Invert= 1,034.25' / 1,033.25' S= 0.0125 '/' Cc= 0.900 n= 0.010 PVC, smooth interior, Flow Area= 0.09 sf

Primary OutFlow Max=0.41 cfs @ 11.92 hrs HW=1,038.39' TW=1,035.69' (Dynamic Tailwater)
1=Culvert (Outlet Controls 0.41 cfs @ 4.69 fps)

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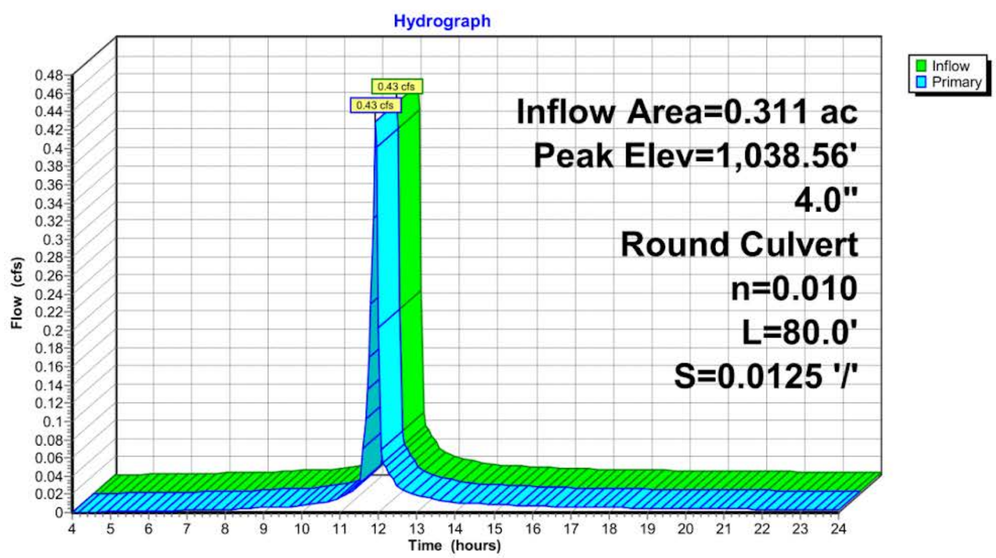
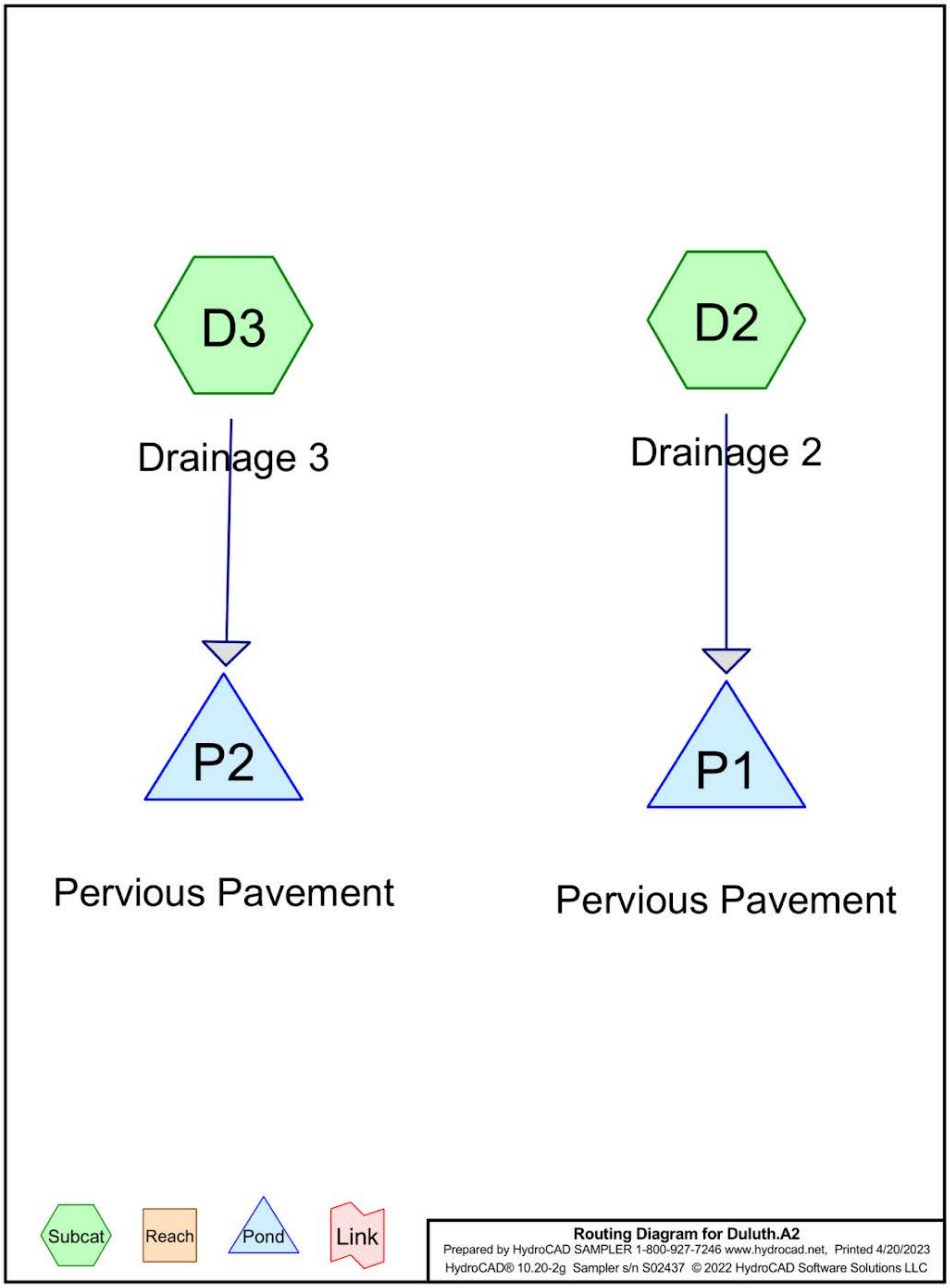
Pond Inlet: Underdrain Inlet



Alternative 2: Pervious Pavement



Area Listing (all nodes)

Area (acres)	CN	Description (subcatchment-numbers)
0.378	74	>75% Grass cover, Good, HSG C (D2, D3)
1.230	98	Paved parking, HSG C (D2)
0.732	98	Water Surface, HSG C (D3)
2.339	**94**	**TOTAL AREA**

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Soil Listing (all nodes)

Area (acres)	Soil Group	Subcatchment Numbers
0.000	HSG A	
0.000	HSG B	
2.339	HSG C	D2, D3
0.000	HSG D	
0.000	Other	
2.339		**TOTAL AREA**

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Ground Covers (all nodes)

HSG-A (acres)	HSG-B (acres)	HSG-C (acres)	HSG-D (acres)	Other (acres)	Total (acres)	Ground Cover	Subcatchment Numbers
0.000	0.000	0.378	0.000	0.000	0.378	>75% Grass cover, Good	D2, D3
0.000	0.000	1.230	0.000	0.000	1.230	Paved parking	D2
0.000	0.000	0.732	0.000	0.000	0.732	Water Surface	D3
0.000	**0.000**	**2.339**	**0.000**	**0.000**	**2.339**	**TOTAL AREA**	

Pipe Listing (all nodes)

Line#	Node Number	In-Invert (feet)	Out-Invert (feet)	Length (feet)	Slope (ft/ft)	n	Width (inches)	Diam/Height (inches)	Inside-Fill (inches)
1	P1	1,037.50	1,034.40	85.0	0.0365	0.010	0.0	4.0	0.0
2	P2	1,038.50	1,035.15	70.0	0.0479	0.010	0.0	4.0	0.0

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Time span=5.00-20.00 hrs, dt=0.05 hrs, 301 points
Runoff by SCS TR-20 method, UH=SCS, Weighted-CN
Reach routing by Stor-Ind+Trans method - Pond routing by Stor-Ind method

Subcatchment D2: Drainage 2 Runoff Area=61,784 sf 86.75% Impervious Runoff Depth>0.52"
Flow Length=638' Tc=6.5 min CN=95 Runoff=1.36 cfs 0.062 af

Subcatchment D3: Drainage 3 Runoff Area=40,122 sf 79.42% Impervious Runoff Depth>0.41"
Flow Length=312' Tc=11.6 min CN=93 Runoff=0.60 cfs 0.032 af

Pond P1: Pervious Pavement Peak Elev=1,037.93' Storage=1,293 cf Inflow=1.36 cfs 0.062 af
Outflow=0.22 cfs 0.055 af

Pond P2: Pervious Pavement Peak Elev=1,038.87' Storage=518 cf Inflow=0.60 cfs 0.032 af
Outflow=0.19 cfs 0.029 af

Total Runoff Area = 2.339 ac Runoff Volume = 0.093 af Average Runoff Depth = 0.48"
16.14% Pervious = 0.378 ac 83.86% Impervious = 1.962 ac

Summary for Subcatchment D2: Drainage 2

Runoff = 1.36 cfs @ 11.98 hrs, Volume= 0.062 af, Depth> 0.52"
Routed to Pond P1 : Pervious Pavement

Runoff by SCS TR-20 method, UH=SCS, Weighted-CN, Time Span= 5.00-20.00 hrs, dt= 0.05 hrs
Type II 24-hr Rainfall=1.00"

Area (sf)	CN	Description
8,189	74	>75% Grass cover, Good, HSG C
53,595	98	Paved parking, HSG C
61,784	95	Weighted Average
8,189		13.25% Pervious Area
53,595		86.75% Impervious Area

Tc (min)	Length (feet)	Slope (ft/ft)	Velocity (ft/sec)	Capacity (cfs)	Description
3.6	100	0.2000	0.46		**Sheet Flow, Grass** Grass: Short n= 0.150 P2= 3.71"
0.5	198	0.2000	7.20		**Shallow Concentrated Flow, Grass** Unpaved Kv= 16.1 fps
1.1	100	0.0220	1.54		**Sheet Flow, Pavement** Smooth surfaces n= 0.011 P2= 3.71"
1.3	240	0.0220	3.01		**Shallow Concentrated Flow, Pavement** Paved Kv= 20.3 fps
6.5	638	Total			

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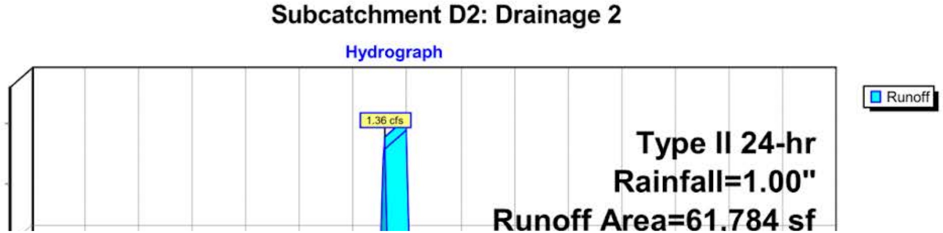
Subcatchment D2: Drainage 2



Summary for Subcatchment D3: Drainage 3

Runoff = 0.60 cfs @ 12.04 hrs, Volume= 0.032 af, Depth> 0.41"
Routed to Pond P2 : Pervious Pavement

Runoff by SCS TR-20 method, UH=SCS, Weighted-CN, Time Span= 5.00-20.00 hrs, dt= 0.05 hrs
Type II 24-hr Rainfall=1.00"

Area (sf)	CN	Description
8,256	74	>75% Grass cover, Good, HSG C
31,866	98	Water Surface, HSG C
40,122	93	Weighted Average
8,256		20.58% Pervious Area
31,866		79.42% Impervious Area

Tc (min)	Length (feet)	Slope (ft/ft)	Velocity (ft/sec)	Capacity (cfs)	Description
8.7	42	0.0040	0.08		**Sheet Flow, Grass** Grass: Short n= 0.150 P2= 3.71"
1.5	100	0.0100	1.12		**Sheet Flow, Pavement** Smooth surfaces n= 0.011 P2= 3.71"
1.4	170	0.0100	2.03		**Shallow Concentrated Flow, Pavement** Paved Kv= 20.3 fps
11.6	312	Total			

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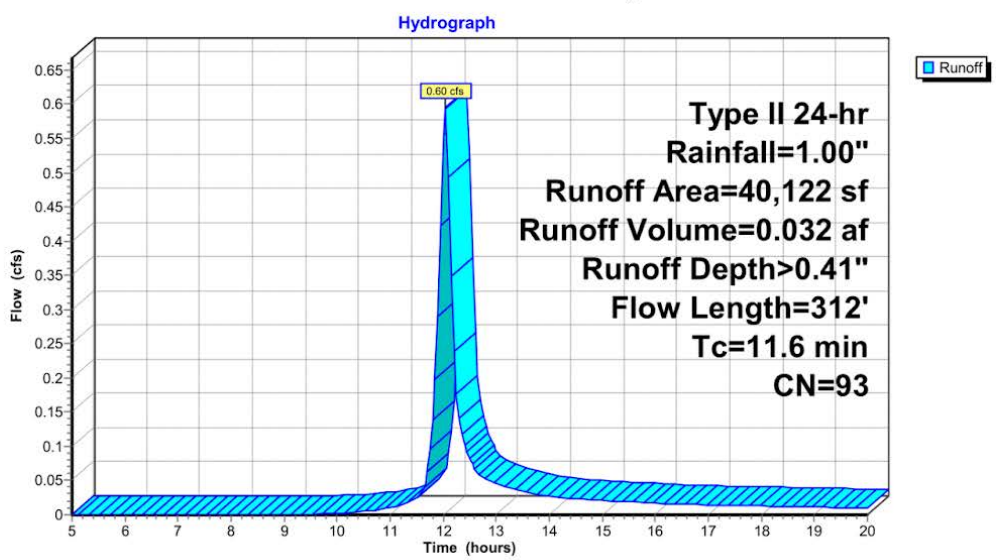
Subcatchment D3: Drainage 3



Summary for Pond P1: Pervious Pavement

Inflow Area = 1.418 ac, 86.75% Impervious, Inflow Depth > 0.52"
Inflow = 1.36 cfs @ 11.98 hrs, Volume= 0.062 af
Outflow = 0.22 cfs @ 12.22 hrs, Volume= 0.055 af, Atten= 84%, Lag= 14.3 min
Primary = 0.22 cfs @ 12.22 hrs, Volume= 0.055 af

Routing by Stor-Ind method, Time Span= 5.00-20.00 hrs, dt= 0.05 hrs
Peak Elev= 1,037.93' @ 12.22 hrs Surf.Area= 7,500 sf Storage= 1,293 cf

Plug-Flow detention time= 110.3 min calculated for 0.055 af (89% of inflow)
Center-of-Mass det. time= 74.4 min (855.6 - 781.1)

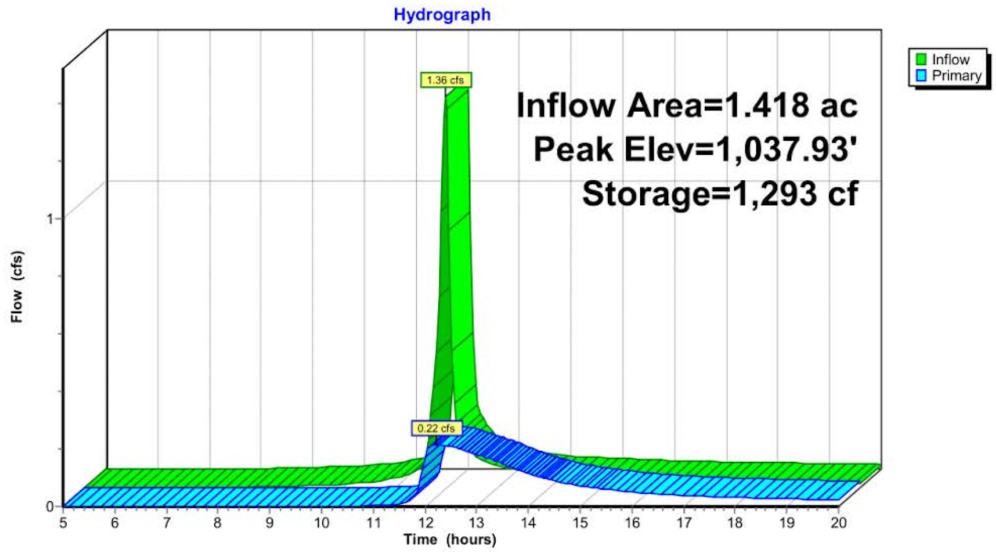
Volume	Invert	Avail.Storage	Storage Description
#1	1,037.50'	7,500 cf	**Custom Stage Data (Prismatic)** Listed below (Recalc) 18,750 cf Overall x 40.0% Voids

Elevation (feet)	Surf.Area (sq-ft)	Inc.Store (cubic-feet)	Cum.Store (cubic-feet)
1,037.50	7,500	0	0
1,040.00	7,500	18,750	18,750

Device	Routing	Invert	Outlet Devices
#1	Primary	1,037.50'	**0.004 in/hr Exfiltration X 0.10 over Surface area**
#2	Primary	1,037.50'	**4.0" Round Culvert** L= 85.0' CMP, square edge headwall, Ke= 0.500 Inlet / Outlet Invert= 1,037.50' / 1,034.40' S= 0.0365 '/' Cc= 0.900 n= 0.010 PVC, smooth interior, Flow Area= 0.09 sf

Primary OutFlow Max=0.22 cfs @ 12.22 hrs HW=1,037.93' (Free Discharge)
↑**1=Exfiltration** (Exfiltration Controls 0.00 cfs)
└**2=Culvert** (Inlet Controls 0.22 cfs @ 2.47 fps)

Pond P1: Pervious Pavement



Summary for Pond P2: Pervious Pavement

Inflow Area = 0.921 ac, 79.42% Impervious, Inflow Depth > 0.41"
Inflow = 0.60 cfs @ 12.04 hrs, Volume= 0.032 af
Outflow = 0.19 cfs @ 12.24 hrs, Volume= 0.029 af, Atten= 68%, Lag= 12.3 min
Primary = 0.19 cfs @ 12.24 hrs, Volume= 0.029 af

Routing by Stor-Ind method, Time Span= 5.00-20.00 hrs, dt= 0.05 hrs
Peak Elev= 1,038.87' @ 12.24 hrs Surf.Area= 3,500 sf Storage= 518 cf

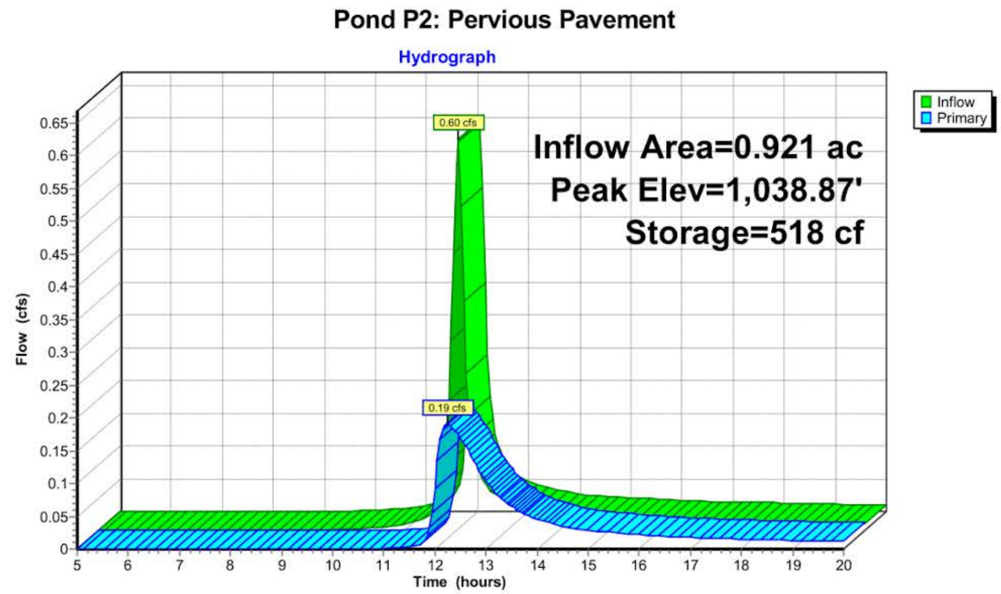
Plug-Flow detention time= 65.5 min calculated for 0.029 af (93% of inflow)
Center-of-Mass det. time= 41.1 min (838.8 - 797.7)

Volume	Invert	Avail.Storage	Storage Description
#1	1,038.50'	3,500 cf	**Custom Stage Data (Prismatic)** Listed below (Recalc) 8,750 cf Overall x 40.0% Voids

Elevation (feet)	Surf.Area (sq-ft)	Inc.Store (cubic-feet)	Cum.Store (cubic-feet)
1,038.50	3,500	0	0
1,041.00	3,500	8,750	8,750

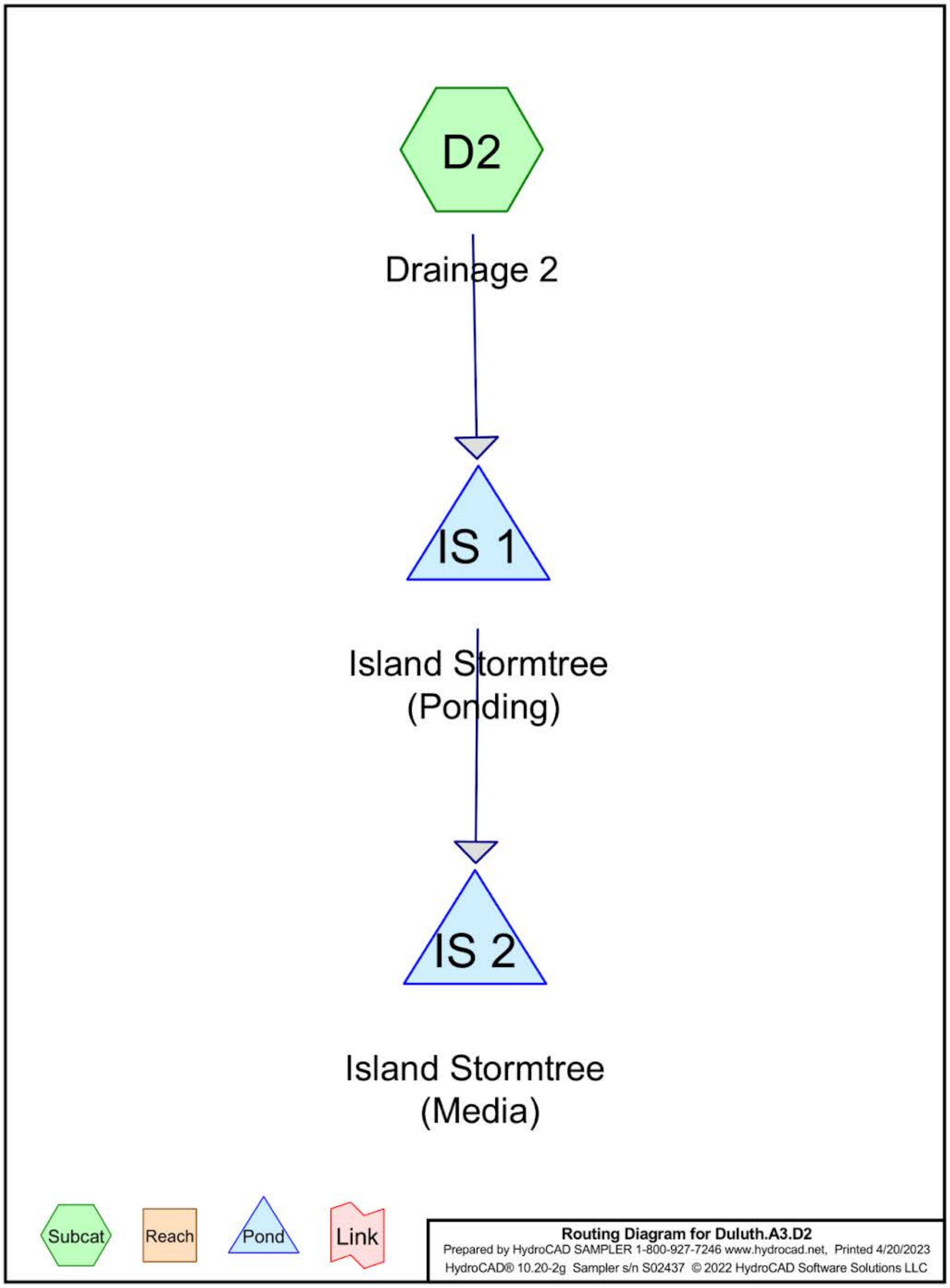
Device	Routing	Invert	Outlet Devices
#1	Primary	1,038.50'	**0.004 in/hr Exfiltration X 0.10 over Surface area**
#2	Primary	1,038.50'	**4.0" Round Culvert** L= 70.0' CMP, square edge headwall, Ke= 0.500 Inlet / Outlet Invert= 1,038.50' / 1,035.15' S= 0.0479 '/' Cc= 0.900 n= 0.010 PVC, smooth interior, Flow Area= 0.09 sf

Primary OutFlow Max=0.19 cfs @ 12.24 hrs HW=1,038.87' (Free Discharge)
1=Exfiltration (Exfiltration Controls 0.00 cfs)
2=Culvert (Inlet Controls 0.19 cfs @ 2.17 fps)


Pond P2: Pervious Pavement
Hydrograph
Inflow
Primary
0.60 cfs
0.19 cfs
Inflow Area=0.921 ac
Peak Elev=1,038.87'
Storage=518 cf
Flow (cfs)
Time (hours)
0.65
0.6
0.55
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20

Alternative 3: StormTree Islands (Drainage Area 2)

*Note: Due to the limited access to the HydroCAD system, the model for StormTree Islands was split into two files, each of which has their own report.



Area Listing (all nodes)

Area (acres)	CN	Description (subcatchment-numbers)
0.188	74	>75% Grass cover, Good, HSG C (D2)
1.230	98	Paved parking, HSG C (D2)
1.418	**95**	**TOTAL AREA**

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Soil Listing (all nodes)

Area (acres)	Soil Group	Subcatchment Numbers
0.000	HSG A	
0.000	HSG B	
1.418	HSG C	D2
0.000	HSG D	
0.000	Other	
1.418		**TOTAL AREA**

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Ground Covers (all nodes)

HSG-A (acres)	HSG-B (acres)	HSG-C (acres)	HSG-D (acres)	Other (acres)	Total (acres)	Ground Cover	Subcatchment Numbers
0.000	0.000	0.188	0.000	0.000	0.188	>75% Grass cover, Good	D2
0.000	0.000	1.230	0.000	0.000	1.230	Paved parking	D2
0.000	**0.000**	**1.418**	**0.000**	**0.000**	**1.418**	**TOTAL AREA**	

Pipe Listing (all nodes)

Line#	Node Number	In-Invert (feet)	Out-Invert (feet)	Length (feet)	Slope (ft/ft)	n	Width (inches)	Diam/Height (inches)	Inside-Fill (inches)
1	IS 2	1,037.75	1,034.75	515.0	0.0058	0.010	0.0	4.0	0.0

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Time span=5.00-20.00 hrs, dt=0.05 hrs, 301 points
Runoff by SCS TR-20 method, UH=SCS, Weighted-CN
Reach routing by Stor-Ind+Trans method - Pond routing by Stor-Ind method

Subcatchment D2: Drainage 2 Runoff Area=61,784 sf 86.75% Impervious Runoff Depth>0.52"
Flow Length=638' Tc=6.5 min CN=95 Runoff=1.36 cfs 0.062 af

Pond IS 1: Island Stormtree (Ponding) Peak Elev=1,041.06' Storage=1,108 cf Inflow=1.36 cfs 0.062 af
Discarded=0.16 cfs 0.027 af Primary=0.05 cfs 0.035 af Outflow=0.21 cfs 0.061 af

Pond IS 2: Island Stormtree (Media) Peak Elev=1,037.91' Storage=221 cf Inflow=0.05 cfs 0.035 af
Discarded=0.00 cfs 0.000 af Primary=0.05 cfs 0.032 af Outflow=0.05 cfs 0.032 af

Total Runoff Area = 1.418 ac Runoff Volume = 0.062 af Average Runoff Depth = 0.52"
13.25% Pervious = 0.188 ac 86.75% Impervious = 1.230 ac

Summary for Subcatchment D2: Drainage 2

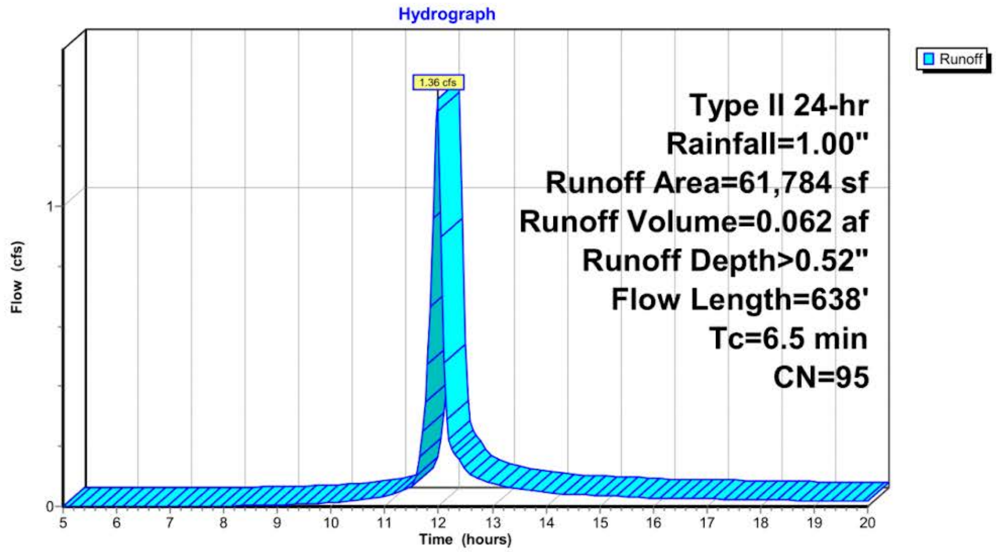
Runoff = 1.36 cfs @ 11.98 hrs, Volume= 0.062 af, Depth> 0.52"
Routed to Pond IS 1 : Island Stormtree (Ponding)

Runoff by SCS TR-20 method, UH=SCS, Weighted-CN, Time Span= 5.00-20.00 hrs, dt= 0.05 hrs
Type II 24-hr Rainfall=1.00"

Area (sf)	CN	Description
8,189	74	>75% Grass cover, Good, HSG C
53,595	98	Paved parking, HSG C
61,784	95	Weighted Average
8,189		13.25% Pervious Area
53,595		86.75% Impervious Area

Tc (min)	Length (feet)	Slope (ft/ft)	Velocity (ft/sec)	Capacity (cfs)	Description
3.6	100	0.2000	0.46		**Sheet Flow, Grass** Grass: Short n= 0.150 P2= 3.71"
0.5	198	0.2000	7.20		**Shallow Concentrated Flow, Grass** Unpaved Kv= 16.1 fps
1.1	100	0.0220	1.54		**Sheet Flow, Pavement** Smooth surfaces n= 0.011 P2= 3.71"
1.3	240	0.0220	3.01		**Shallow Concentrated Flow, Pavement** Paved Kv= 20.3 fps
6.5	638	Total			

Subcatchment D2: Drainage 2



Summary for Pond IS 1: Island Stormtree (Ponding)

Inflow Area = 1.418 ac, 86.75% Impervious, Inflow Depth > 0.52"
Inflow = 1.36 cfs @ 11.98 hrs, Volume= 0.062 af
Outflow = 0.21 cfs @ 12.22 hrs, Volume= 0.061 af, Atten= 84%, Lag= 14.6 min
Discarded = 0.16 cfs @ 12.22 hrs, Volume= 0.027 af
Primary = 0.05 cfs @ 11.45 hrs, Volume= 0.035 af
Routed to Pond IS 2 : Island Stormtree (Media)

Routing by Stor-Ind method, Time Span= 5.00-20.00 hrs, dt= 0.05 hrs
Peak Elev= 1,041.06' @ 12.22 hrs Surf.Area= 3,536 sf Storage= 1,108 cf

Plug-Flow detention time= 68.3 min calculated for 0.061 af (100% of inflow)
Center-of-Mass det. time= 67.0 min (848.1 - 781.1)

Volume	Invert	Avail.Storage	Storage Description
#1	1,040.75'	2,652 cf	**Custom Stage Data (Prismatic)** Listed below (Recalc)

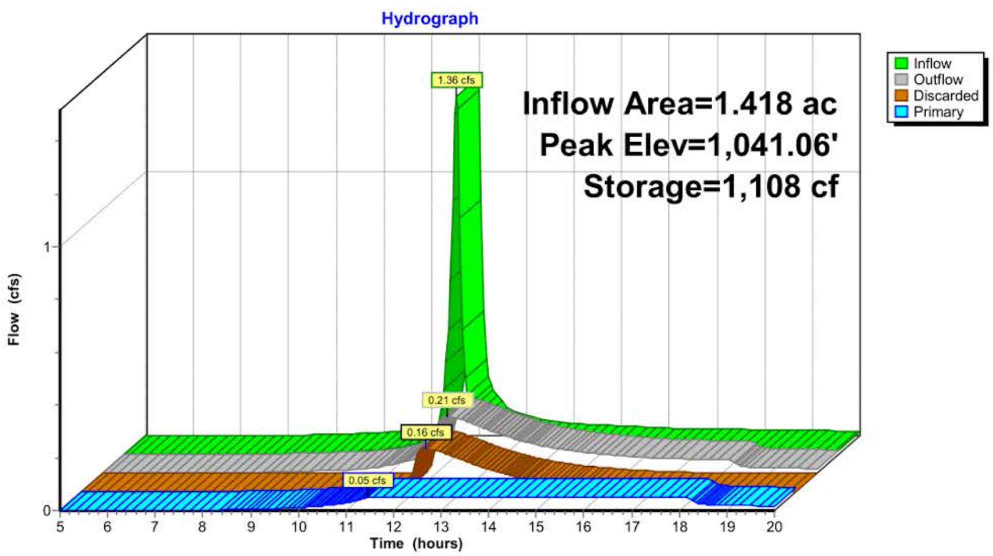
Elevation (feet)	Surf.Area (sq-ft)	Inc.Store (cubic-feet)	Cum.Store (cubic-feet)
1,040.75	3,536	0	0
1,041.50	3,536	2,652	2,652

Device	Routing	Invert	Outlet Devices
#1	Primary	1,040.75'	**0.05 cfs Exfiltration at all elevations**
#2	Discarded	1,040.75'	**4.0" Vert. Orifice/Grate** C= 0.600 Limited to weir flow at low heads

Discarded OutFlow Max=0.16 cfs @ 12.22 hrs HW=1,041.06' (Free Discharge)
└**2=Orifice/Grate** (Orifice Controls 0.16 cfs @ 1.91 fps)

Primary OutFlow Max=0.05 cfs @ 11.45 hrs HW=1,040.76' (Free Discharge)
└**1=Exfiltration** (Exfiltration Controls 0.05 cfs)

Pond IS 1: Island Stormtree (Ponding)



Summary for Pond IS 2: Island Stormtree (Media)

Update outlets

Inflow Area = 1.418 ac, 86.75% Impervious, Inflow Depth > 0.30"
Inflow = 0.05 cfs @ 11.45 hrs, Volume= 0.035 af
Outflow = 0.05 cfs @ 18.15 hrs, Volume= 0.032 af, Atten= 0%, Lag= 402.0 min
Discarded = 0.00 cfs @ 10.25 hrs, Volume= 0.000 af
Primary = 0.05 cfs @ 18.15 hrs, Volume= 0.032 af

Routing by Stor-Ind method, Time Span= 5.00-20.00 hrs, dt= 0.05 hrs
Peak Elev= 1,037.91' @ 18.15 hrs Surf.Area= 3,536 sf Storage= 221 cf

Plug-Flow detention time= 75.1 min calculated for 0.031 af (90% of inflow)
Center-of-Mass det. time= 48.6 min (932.9 - 884.3)

Volume	Invert	Avail.Storage	Storage Description
#1	1,037.75'	4,243 cf	**Custom Stage Data (Prismatic)** Listed below (Recalc) 10,608 cf Overall x 40.0% Voids

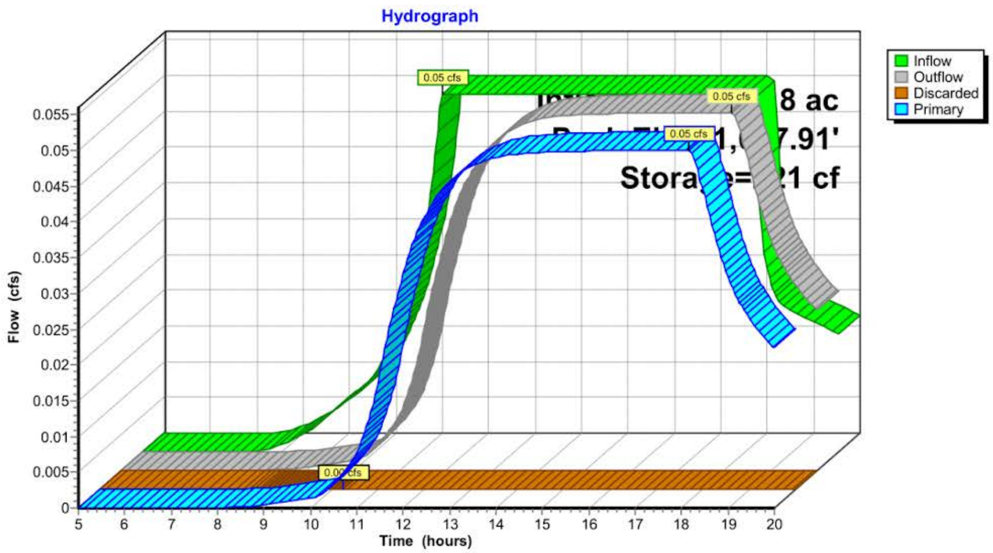
Elevation (feet)	Surf.Area (sq-ft)	Inc.Store (cubic-feet)	Cum.Store (cubic-feet)
1,037.75	3,536	0	0
1,040.75	3,536	10,608	10,608

Device	Routing	Invert	Outlet Devices
#1	Discarded	1,037.75'	**0.005 in/hr Exfiltration X 0.10 over Surface area**
#2	Primary	1,037.75'	**4.0" Round Culvert** L= 515.0' CPP, square edge headwall, Ke= 0.500 Inlet / Outlet Invert= 1,037.75' / 1,034.75' S= 0.0058 '/' Cc= 0.900 n= 0.010 PVC, smooth interior, Flow Area= 0.09 sf

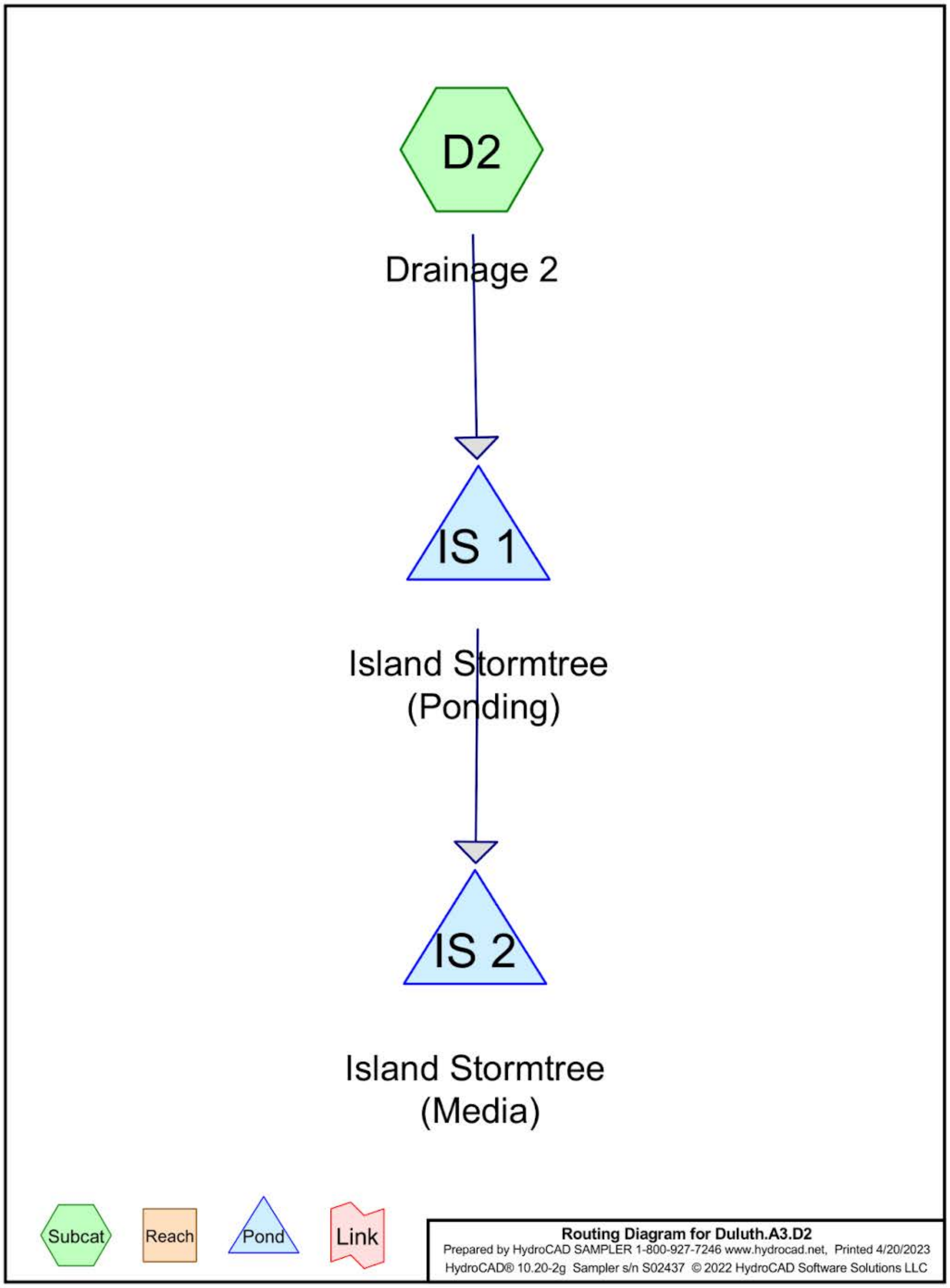
Discarded OutFlow Max=0.00 cfs @ 10.25 hrs HW=1,037.78' (Free Discharge)
└─**1=Exfiltration** (Exfiltration Controls 0.00 cfs)

Primary OutFlow Max=0.05 cfs @ 18.15 hrs HW=1,037.91' (Free Discharge)
└─**2=Culvert** (Barrel Controls 0.05 cfs @ 1.82 fps)

Pond IS 2: Island Stormtree (Media)



Alternative 3: StormTree Islands (Drainage Area 3)



Area Listing (all nodes)

Area (acres)	CN	Description (subcatchment-numbers)
0.188	74	>75% Grass cover, Good, HSG C (D2)
1.230	98	Paved parking, HSG C (D2)
1.418	**95**	**TOTAL AREA**

Soil Listing (all nodes)

Area (acres)	Soil Group	Subcatchment Numbers
0.000	HSG A	
0.000	HSG B	
1.418	HSG C	D2
0.000	HSG D	
0.000	Other	
1.418		**TOTAL AREA**

Ground Covers (all nodes)

HSG-A (acres)	HSG-B (acres)	HSG-C (acres)	HSG-D (acres)	Other (acres)	Total (acres)	Ground Cover	Subcatchment Numbers
0.000	0.000	0.188	0.000	0.000	0.188	>75% Grass cover, Good	D2
0.000	0.000	1.230	0.000	0.000	1.230	Paved parking	D2
0.000	**0.000**	**1.418**	**0.000**	**0.000**	**1.418**	**TOTAL AREA**	

Pipe Listing (all nodes)

Line#	Node Number	In-Invert (feet)	Out-Invert (feet)	Length (feet)	Slope (ft/ft)	n	Width (inches)	Diam/Height (inches)	Inside-Fill (inches)
1	IS 2	1,037.75	1,034.75	515.0	0.0058	0.010	0.0	4.0	0.0

Time span=5.00-20.00 hrs, dt=0.05 hrs, 301 points
Runoff by SCS TR-20 method, UH=SCS, Weighted-CN
Reach routing by Stor-Ind+Trans method - Pond routing by Stor-Ind method

Subcatchment D3: Drainage 3 Runoff Area=40,122 sf 79.42% Impervious Runoff Depth>0.41"
Flow Length=312' Tc=11.6 min CN=93 Runoff=0.60 cfs 0.032 af

Pond IS 1: Island Stormtree (Ponding) Peak Elev=1,040.94' Storage=497 cf Inflow=0.60 cfs 0.032 af
Discarded=0.07 cfs 0.008 af Primary=0.05 cfs 0.023 af Outflow=0.12 cfs 0.032 af

Pond IS 2: Island Stormtree (Media) Peak Elev=1,037.90' Storage=159 cf Inflow=0.05 cfs 0.023 af
Discarded=0.00 cfs 0.000 af Primary=0.05 cfs 0.021 af Outflow=0.05 cfs 0.021 af

Total Runoff Area = 0.921 ac Runoff Volume = 0.032 af Average Runoff Depth = 0.41"
20.58% Pervious = 0.190 ac 79.42% Impervious = 0.732 ac

Summary for Subcatchment D2: Drainage 2

Runoff = 1.36 cfs @ 11.98 hrs, Volume= 0.062 af, Depth> 0.52"
Routed to Pond IS 1 : Island Stormtree (Ponding)

Runoff by SCS TR-20 method, UH=SCS, Weighted-CN, Time Span= 5.00-20.00 hrs, dt= 0.05 hrs
Type II 24-hr Rainfall=1.00"

Area (sf)	CN	Description
8,189	74	>75% Grass cover, Good, HSG C
53,595	98	Paved parking, HSG C
61,784	95	Weighted Average
8,189		13.25% Pervious Area
53,595		86.75% Impervious Area

Tc (min)	Length (feet)	Slope (ft/ft)	Velocity (ft/sec)	Capacity (cfs)	Description
3.6	100	0.2000	0.46		**Sheet Flow, Grass** Grass: Short n= 0.150 P2= 3.71"
0.5	198	0.2000	7.20		**Shallow Concentrated Flow, Grass** Unpaved Kv= 16.1 fps
1.1	100	0.0220	1.54		**Sheet Flow, Pavement** Smooth surfaces n= 0.011 P2= 3.71"
1.3	240	0.0220	3.01		**Shallow Concentrated Flow, Pavement** Paved Kv= 20.3 fps
6.5	638	Total			

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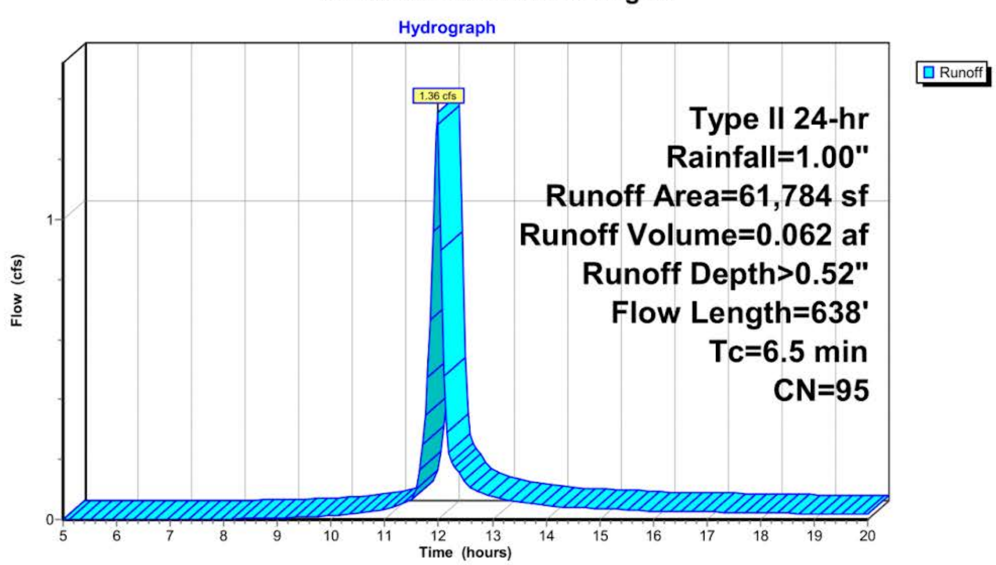
Subcatchment D2: Drainage 2



Summary for Pond IS 1: Island Stormtree (Ponding)

Inflow Area = 1.418 ac, 86.75% Impervious, Inflow Depth > 0.52"
Inflow = 1.36 cfs @ 11.98 hrs, Volume= 0.062 af
Outflow = 0.21 cfs @ 12.22 hrs, Volume= 0.061 af, Atten= 84%, Lag= 14.6 min
Discarded = 0.16 cfs @ 12.22 hrs, Volume= 0.027 af
Primary = 0.05 cfs @ 11.45 hrs, Volume= 0.035 af
Routed to Pond IS 2 : Island Stormtree (Media)

Routing by Stor-Ind method, Time Span= 5.00-20.00 hrs, dt= 0.05 hrs
Peak Elev= 1,041.06' @ 12.22 hrs Surf.Area= 3,536 sf Storage= 1,108 cf

Plug-Flow detention time= 68.3 min calculated for 0.061 af (100% of inflow)
Center-of-Mass det. time= 67.0 min (848.1 - 781.1)

Volume	Invert	Avail.Storage	Storage Description
#1	1,040.75'	2,652 cf	**Custom Stage Data (Prismatic)** Listed below (Recalc)

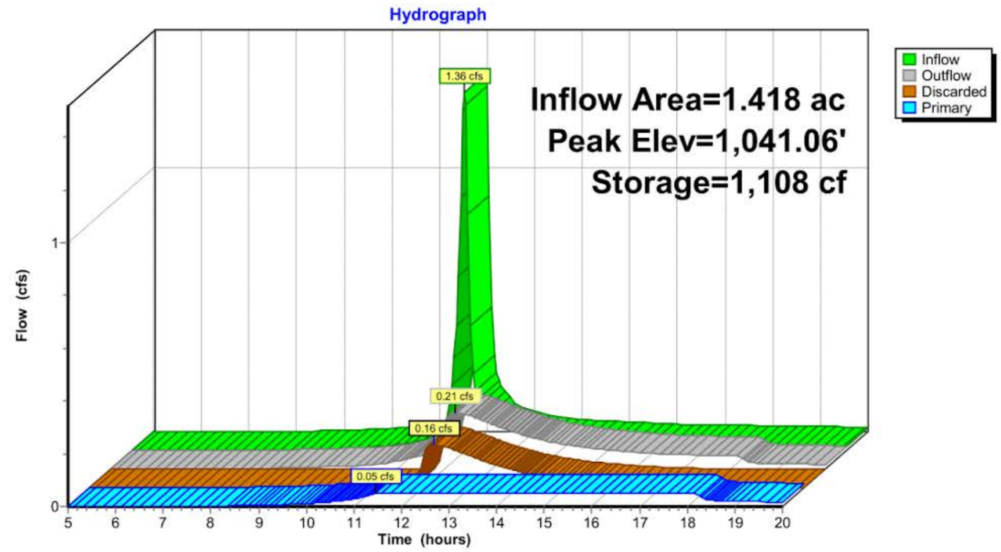
Elevation (feet)	Surf.Area (sq-ft)	Inc.Store (cubic-feet)	Cum.Store (cubic-feet)
1,040.75	3,536	0	0
1,041.50	3,536	2,652	2,652

Device	Routing	Invert	Outlet Devices
#1	Primary	1,040.75'	**0.05 cfs Exfiltration at all elevations**
#2	Discarded	1,040.75'	**4.0" Vert. Orifice/Grate** C= 0.600 Limited to weir flow at low heads

Discarded OutFlow Max=0.16 cfs @ 12.22 hrs HW=1,041.06' (Free Discharge)
↑—**2=Orifice/Grate** (Orifice Controls 0.16 cfs @ 1.91 fps)

Primary OutFlow Max=0.05 cfs @ 11.45 hrs HW=1,040.76' (Free Discharge)
↑—**1=Exfiltration** (Exfiltration Controls 0.05 cfs)

Pond IS 1: Island Stormtree (Ponding)



Summary for Pond IS 2: Island Stormtree (Media)

Update outlets

Inflow Area =	1.418 ac, 86.75% Impervious, Inflow Depth > 0.30"		
Inflow =	0.05 cfs @ 11.45 hrs, Volume=	0.035 af	
Outflow =	0.05 cfs @ 18.15 hrs, Volume=	0.032 af,	Atten= 0%, Lag= 402.0 min
Discarded =	0.00 cfs @ 10.25 hrs, Volume=	0.000 af	
Primary =	0.05 cfs @ 18.15 hrs, Volume=	0.032 af	

Routing by Stor-Ind method, Time Span= 5.00-20.00 hrs, dt= 0.05 hrs
Peak Elev= 1,037.91' @ 18.15 hrs Surf.Area= 3,536 sf Storage= 221 cf

Plug-Flow detention time= 75.1 min calculated for 0.031 af (90% of inflow)
Center-of-Mass det. time= 48.6 min (932.9 - 884.3)

Volume	Invert	Avail.Storage	Storage Description
#1	1,037.75'	4,243 cf	**Custom Stage Data (Prismatic)** Listed below (Recalc) 10,608 cf Overall x 40.0% Voids

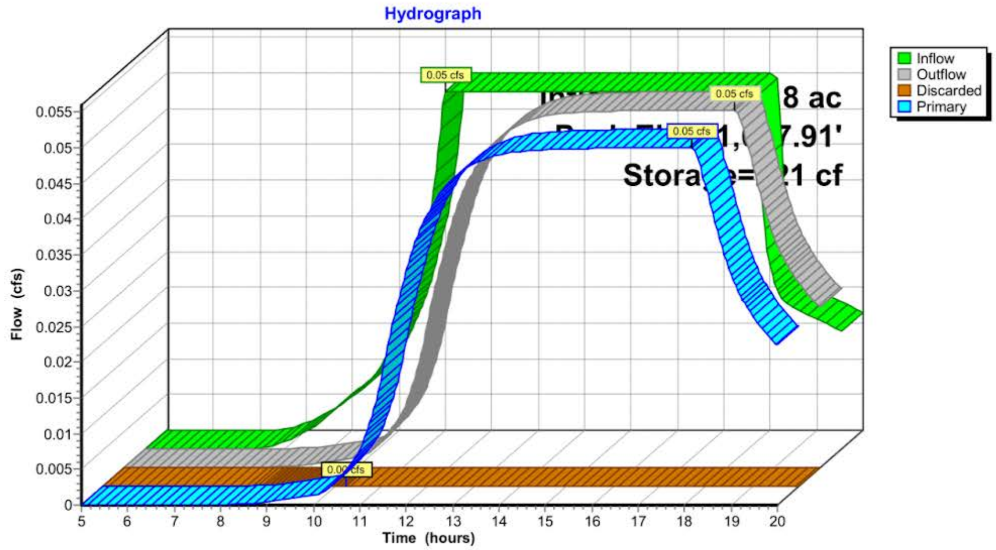
Elevation (feet)	Surf.Area (sq-ft)	Inc.Store (cubic-feet)	Cum.Store (cubic-feet)
1,037.75	3,536	0	0
1,040.75	3,536	10,608	10,608

Device	Routing	Invert	Outlet Devices
#1	Discarded	1,037.75'	**0.005 in/hr Exfiltration X 0.10 over Surface area**
#2	Primary	1,037.75'	**4.0" Round Culvert** L= 515.0' CPP, square edge headwall, Ke= 0.500 Inlet / Outlet Invert= 1,037.75' / 1,034.75' S= 0.0058 '/' Cc= 0.900 n= 0.010 PVC, smooth interior, Flow Area= 0.09 sf

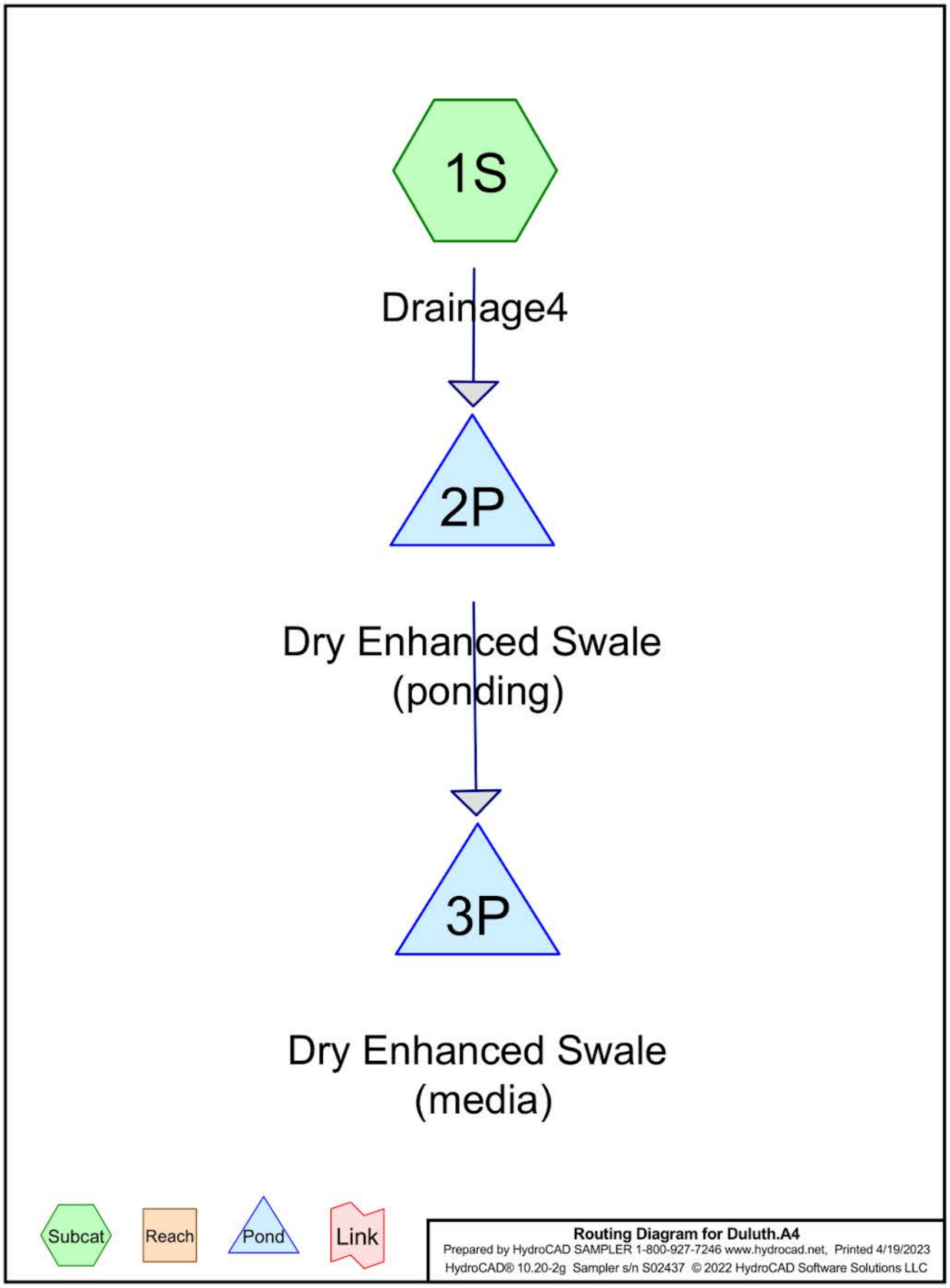
Discarded OutFlow Max=0.00 cfs @ 10.25 hrs HW=1,037.78' (Free Discharge)
└─**1=Exfiltration** (Exfiltration Controls 0.00 cfs)

Primary OutFlow Max=0.05 cfs @ 18.15 hrs HW=1,037.91' (Free Discharge)
└─**2=Culvert** (Barrel Controls 0.05 cfs @ 1.82 fps)

Pond IS 2: Island Stormtree (Media)



Alternative 4: Dry Enhanced Swale



Area Listing (all nodes)

Area (acres)	CN	Description (subcatchment-numbers)
0.566	74	>75% Grass cover, Good, HSG C (1S)
0.294	98	Water Surface, HSG C (1S)
0.860	**82**	**TOTAL AREA**

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Soil Listing (all nodes)

Area (acres)	Soil Group	Subcatchment Numbers
0.000	HSG A	
0.000	HSG B	
0.860	HSG C	1S
0.000	HSG D	
0.000	Other	
0.860		**TOTAL AREA**

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Ground Covers (all nodes)

HSG-A (acres)	HSG-B (acres)	HSG-C (acres)	HSG-D (acres)	Other (acres)	Total (acres)	Ground Cover	Subcatchment Numbers
0.000	0.000	0.566	0.000	0.000	0.566	>75% Grass cover, Good	1S
0.000	0.000	0.294	0.000	0.000	0.294	Water Surface	1S
0.000	**0.000**	**0.860**	**0.000**	**0.000**	**0.860**	**TOTAL AREA**	

Pipe Listing (all nodes)

Line#	Node Number	In-Invert (feet)	Out-Invert (feet)	Length (feet)	Slope (ft/ft)	n	Width (inches)	Diam/Height (inches)	Inside-Fill (inches)
1	3P	1,034.00	1,015.00	190.0	0.1000	0.010	0.0	4.0	0.0

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Time span=5.00-20.00 hrs, dt=0.05 hrs, 301 points
Runoff by SCS TR-20 method, UH=SCS, Weighted-CN
Reach routing by Stor-Ind+Trans method - Pond routing by Stor-Ind method

Subcatchment 1S: Drainage4 Runoff Area=37,479 sf 34.22% Impervious Runoff Depth>0.10"
Flow Length=551' Tc=10.2 min CN=82 Runoff=0.09 cfs 0.007 af

Pond 2P: Dry Enhanced Swale (ponding) Peak Elev=1,036.60' Storage=136 cf Inflow=0.09 cfs 0.007 af
Outflow=0.01 cfs 0.004 af

Pond 3P: Dry Enhanced Swale (media) Peak Elev=1,034.05' Storage=23 cf Inflow=0.01 cfs 0.004 af
Discarded=0.00 cfs 0.000 af Primary=0.01 cfs 0.004 af Outflow=0.01 cfs 0.004 af

Total Runoff Area = 0.860 ac Runoff Volume = 0.007 af Average Runoff Depth = 0.10"
65.78% Pervious = 0.566 ac 34.22% Impervious = 0.294 ac

Summary for Subcatchment 1S: Drainage4

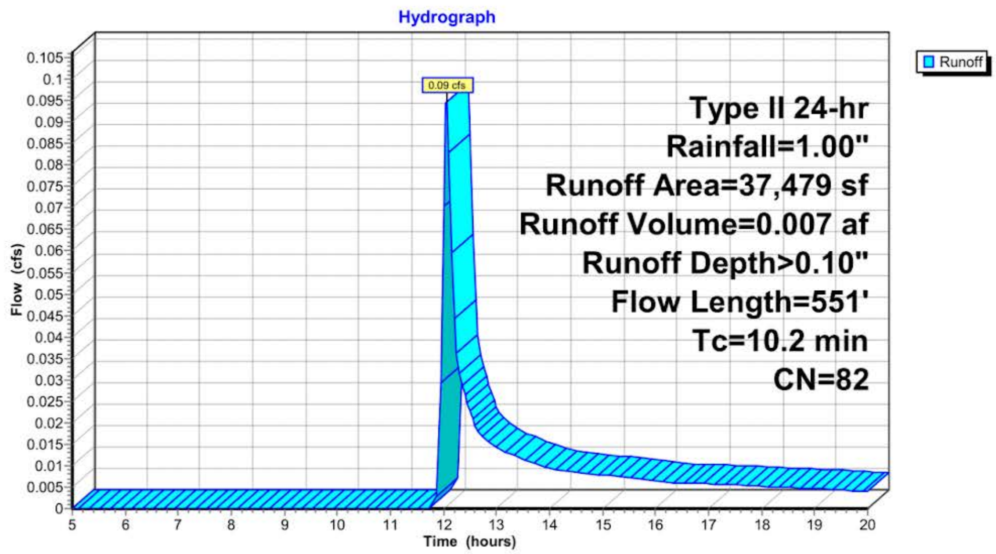
Runoff = 0.09 cfs @ 12.06 hrs, Volume= 0.007 af, Depth> 0.10"
Routed to Pond 2P : Dry Enhanced Swale (ponding)

Runoff by SCS TR-20 method, UH=SCS, Weighted-CN, Time Span= 5.00-20.00 hrs, dt= 0.05 hrs
Type II 24-hr Rainfall=1.00"

Area (sf)	CN	Description
24,652	74	>75% Grass cover, Good, HSG C
12,827	98	Water Surface, HSG C
37,479	82	Weighted Average
24,652		65.78% Pervious Area
12,827		34.22% Impervious Area

Tc (min)	Length (feet)	Slope (ft/ft)	Velocity (ft/sec)	Capacity (cfs)	Description
7.2	100	0.0360	0.23		**Sheet Flow, Grass** Grass: Short n= 0.150 P2= 3.71"
0.1	26	0.0360	3.05		**Shallow Concentrated Flow, Grass** Unpaved Kv= 16.1 fps
1.1	100	0.0220	1.54		**Sheet Flow, Pavement** Smooth surfaces n= 0.011 P2= 3.71"
1.8	325	0.0220	3.01		**Shallow Concentrated Flow, Pavement** Paved Kv= 20.3 fps
10.2	551	Total			

Subcatchment 1S: Drainage4



Summary for Pond 2P: Dry Enhanced Swale (ponding)

Inflow Area = 0.860 ac, 34.22% Impervious, Inflow Depth > 0.10"
Inflow = 0.09 cfs @ 12.06 hrs, Volume= 0.007 af
Outflow = 0.01 cfs @ 16.02 hrs, Volume= 0.004 af, Atten= 93%, Lag= 237.5 min
Primary = 0.01 cfs @ 16.02 hrs, Volume= 0.004 af
Routed to Pond 3P : Dry Enhanced Swale (media)

Routing by Stor-Ind method, Time Span= 5.00-20.00 hrs, dt= 0.05 hrs
Peak Elev= 1,036.60' @ 16.02 hrs Surf.Area= 1,370 sf Storage= 136 cf

Plug-Flow detention time= 200.1 min calculated for 0.004 af (60% of inflow)
Center-of-Mass det. time= 101.5 min (961.2 - 859.7)

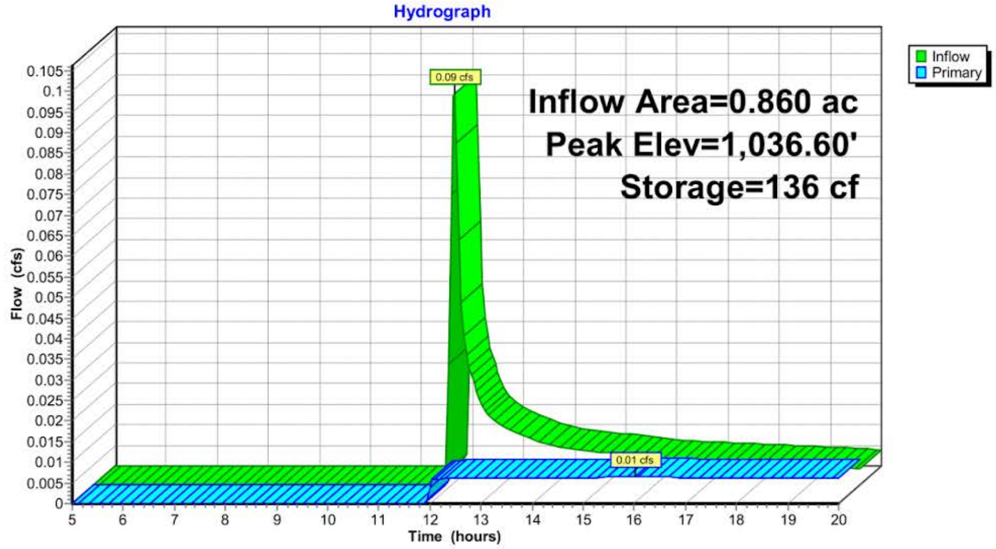
Volume	Invert	Avail.Storage	Storage Description
#1	1,036.50'	3,255 cf	**Custom Stage Data (Prismatic)** Listed below (Recalc)

Elevation (feet)	Surf.Area (sq-ft)	Inc.Store (cubic-feet)	Cum.Store (cubic-feet)
1,036.50	1,240	0	0
1,038.00	3,100	3,255	3,255

Device	Routing	Invert	Outlet Devices
#1	Primary	1,036.50'	**2.000 in/hr Exfiltration X 0.10 over Surface area**

Primary OutFlow Max=0.01 cfs @ 16.02 hrs HW=1,036.60' (Free Discharge)
└─**1=Exfiltration** (Exfiltration Controls 0.01 cfs)

Pond 2P: Dry Enhanced Swale (ponding)



Summary for Pond 3P: Dry Enhanced Swale (media)

Update storage elevation

Inflow Area = 0.860 ac, 34.22% Impervious, Inflow Depth > 0.06"
Inflow = 0.01 cfs @ 16.02 hrs, Volume= 0.004 af
Outflow = 0.01 cfs @ 17.35 hrs, Volume= 0.004 af, Atten= 0%, Lag= 80.0 min
Discarded = 0.00 cfs @ 12.65 hrs, Volume= 0.000 af
Primary = 0.01 cfs @ 17.35 hrs, Volume= 0.004 af

Routing by Stor-Ind method, Time Span= 5.00-20.00 hrs, dt= 0.05 hrs
Peak Elev= 1,034.05' @ 17.35 hrs Surf.Area= 465 sf Storage= 23 cf

Plug-Flow detention time= 58.9 min calculated for 0.004 af (87% of inflow)
Center-of-Mass det. time= 28.4 min (989.6 - 961.2)

Volume	Invert	Avail.Storage	Storage Description
#1	1,034.00'	1,163 cf	**Custom Stage Data (Prismatic)** Listed below (Recalc)

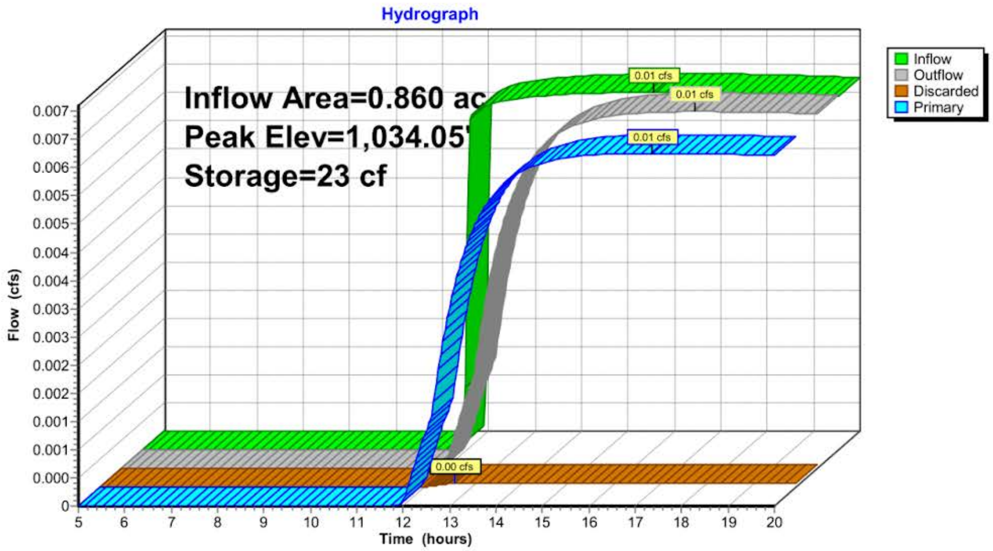
Elevation (feet)	Surf.Area (sq-ft)	Inc.Store (cubic-feet)	Cum.Store (cubic-feet)
1,034.00	465	0	0
1,036.50	465	1,163	1,163

Device	Routing	Invert	Outlet Devices
#1	Discarded	1,034.00'	**0.007 in/hr Exfiltration over Surface area**
#2	Primary	1,034.00'	**4.0" Round Culvert** L= 190.0' CMP, square edge headwall, Ke= 0.500 Inlet / Outlet Invert= 1,034.00' / 1,015.00' S= 0.1000 '/' Cc= 0.900 n= 0.010 PVC, smooth interior, Flow Area= 0.09 sf

Discarded OutFlow Max=0.00 cfs @ 12.65 hrs HW=1,034.03' (Free Discharge)
└─**1=Exfiltration** (Exfiltration Controls 0.00 cfs)

Primary OutFlow Max=0.01 cfs @ 17.35 hrs HW=1,034.05' (Free Discharge)
└─**2=Culvert** (Inlet Controls 0.01 cfs @ 0.76 fps)

Pond 3P: Dry Enhanced Swale (media)



Appendix F: Trench Drain Design

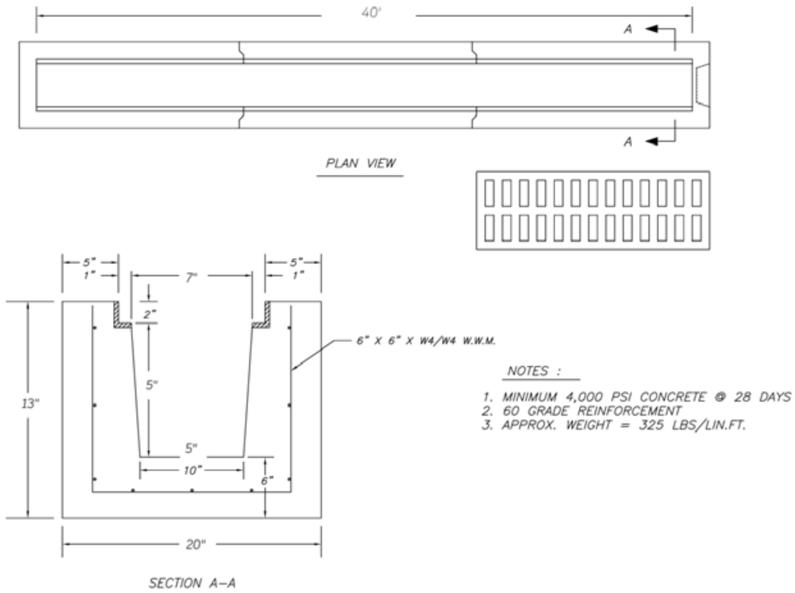


Figure 18: Trench Drain Schematic (Adapted from Precast Concrete Sales)

Appendix G: Construction Estimates

Table F-1: Full Cost Estimation Details for Bioretention Basin

No.	Line Item	Quantity	Unit	Cost/Unit	Total
Bioretention Basin					
1	Excavation and Fill	874	CY	$15.49	$13,600.00
2	Growing Media	228	CY	$107.10	$24,500.00
3	Native Plants	558	EA	$45.46	$25,400.00
4	Grass filter Strip	847	SY	$12.61	$10,700.00
5	Fine Shredded hardwood mulch	16	CY	$67.04	$1,100.00
6	Overflow Pipe Cap	1	EA	$8.95	$100.00
7	Concrete Stone Pavers	1783	SF	$9.26	$20,600.00
8	#8 Washed Choker Stone	46	Ton	$72.13	$3,400.00
9	#57 Washed Stone	69	Ton	$65.93	$4,600.00
10	4" Diameter Solid Wall PVC (Outflow)	205	LF	$8.65	$1,800.00
11	Perforated 4" PVC Pipe (Underdrain)	50	LF	$6.02	$500.00
12	T-connection (4")	1	EA	$141.50	$300.00
13	4" Diameter Solid Wall PVC (Overflow)	4	LF	$8.65	$100.00
14	Saw Cut Concrete	8	LF	$1.25	$100.00
15	Pavement Removal	0.31	CY	$95.60	$100.00
16	Interpretative Sign	3	EA	$1,372.05	$4,200.00
				Subtotal	**$111,100.00**
				Engineering (15%)	**$16,665.00**
				Mobilization (5%)	**$5,555.00**
				Permits and Insurance (5%)	**$5,555.00**
				Subtotal	**$138,875.00**
				Contingency (20%)	**$27,775.00**
				Total	**$166,700.00**

Tables F-2 and F-3 show two different methods for installing the pervious pavement suggested in Alternative 2. Although the installation of StormCrete is suggested due to its precast structure; full cost estimates are provided for both removable StormCrete panels and poured concrete.

Table F-2: Full Cost Estimation Details for Pervious Pavement with Specialty StormCrete

No.	Line Item	Quantity	Unit	Cost/Unit	Total
Pervious Pavement					
1	Excavation and Fill	883	CY	$15.49	$13,700
2	Pavement Material and Delivery	11000	SF	$20.00	$220,000
3	3/8" stone (#8)	82	ton	$72.13	$6,000
4	3/4" stone (#57)	901	ton	$65.83	$59,400
5	4" Diameter Solid Wall PVC (Outflow)	150	LF	$4.93	$800
6	Pavement Removal	136	CY	$95.60	$13,100
7	Perforated 4" PVC Pipe (Underdrain)	310	LF	$6.02	$2,400
8	Interpretative Sign	1	EA	$1,372.05	$1,400
			Subotal (With StormCrete)		**$316,800**
			Engineering (15%)		**$47,520**
			Mobilization (5%)		**$15,840**
			Permits and Insurance (5%)		**$15,840**
			Subtotal		**$396,000**
			Contingency (20%)		**$79,200**
			Total		**$475,200**

Table F-3: Full Cost Estimation Details for Pervious Pavement with Pour-in Pavement

No.	Line Item	Quantity	Unit	Cost/Unit	Total
Pervious Pavement					
1	Excavation and Fill	883	CY	$15.49	$13,700
2	Pervious Pavement	204	CY	$511.44	$104,200
3	3/8" stone (#8)	82	ton	$72.13	$6,000
4	3/4" stone (#57)	901	ton	$65.83	$59,400
5	4" Diameter Solid Wall PVC (Outflow)	155	LF	$4.93	$800
6	Pavement Removal	136	CY	$95.60	$13,100
7	Perforated 4" PVC Pipe (Underdrain)	310	LF	$6.02	$2,400
8	Interpretative Sign	1	EA	$1,372.05	$1,400
			Subtotal (With Pour Down)		**$201,000**
			Engineering (15%)		**$30,150**
			Mobilization (5%)		**$10,050**
			Permits and Insurance (5%)		**$10,050**
			Subtotal		**$251,250**
			Contingency (20%)		**$50,250**
			Total		**$301,500**

Table F-4: Full Cost Estimation Details for StormTree Islands Per Island

No.	Line Item	Quantity	Unit	Cost/Unit	Total
Islands					
1	Excavation and Fill	67	CY	$15.49	$1,100
2	Overflow Pipe Cap	1	EA	$8.95	$100
3	Class AA1 Concrete	14	CY	$393.58	$6,700
4	Native Plants	55	EA	$45.46	$2,600
5	Fine shredded hardwood mulch	3	Ton	$67.04	$300
6	#8 Washed Choker Stone	7	Ton	$72.13	$600
7	#57 Washed Stone	10	Ton	$65.93	$700
8	Growing Media	31	Ton	$107.10	$3,400
9	Perforated 4" PVC Pipe (Underdrain)	13	LF	$6.02	$200
10	4" Diameter Solid Wall PVC (Outflow)	48	LF	$8.65	$500
11	T-connection (4")	1	EA	$141.50	$300
12	4" Diameter Solid Wall PVC (Overflow)	3.75	LF	$8.65	$100
13	Interpretative Sign	1	EA	$1,372.05	$1,400
14	Pavement Removal	13	CY	$95.60	$1,300
				Subtotal	**$16,700**
				Engineering (15%)	**$2,505**
				Mobilization (5%)	**$835**
				Permits and Insurance (5%)	**$835**
				Subtotal	**$20,875**
				Contingency (20%)	**$4,175**
				Total	**$25,050**

*Note: Although the cost estimate is performed in order to calculate the unit cost for one island, there is only intended to be one interpretative sign installed for all of the islands installed. For the purpose of this project, the total cost for the sign was divided by the number of intended installed islands (14) and was added to the remaining line items. The entire cost of the sign is accounted for in the total cost for the 14 islands.

Table F-5: Full Cost Estimation Details for Dry Enhanced Swale

No.	Line Item	Quantity	Unit	Cost/Unit	Total
Swale					
1	Excavation and Fill	165	CY	$15.49	$2,600
2	Permeable Soil	124	CY	$107.10	$13,300
3	Filter Fabric	138	SY	$3.00	$500
4	Gravel	30	CY/Ton	$198.65	$6,000
5	Perforated Pipe (Underdrain, 4")	233	LF	$5.10	$1,500
6	4" Diameter Solid Wall PVC (Outflow)	90	LF	$4.93	$700
7	Grass/Sod	3158	SF	$12.61	$39,900
8	Trench Drains	20	EA	$272.63	$5,500
9	Pavement Removal	1.23	CY	$95.60	$200
10	Interpretative Sign	1	EA	$1,372.05	$1,400
11	Stainless Steel Weir	1	EA	$5,574.62	$5,600
				Subtotal	**$77,200**
				Engineering (15%)	**$11,580**
				Mobilization (5%)	**$3,860**
				Permits and Insurance (5%)	**$3,860**
				Subtotal	**$96,500**
				Contingency (20%)	**$19,300**
				Total	**$115,800**

Table F-6: Full Cost Estimation Details Rain Garden, Per Planter

No.	Line Item	Quantity	Unit	Cost/Unit	Total
Rain Garden					
1	Excavation and Fill	6	CY	$15.49	$100
2	No. 3 Stone	3	Ton	$64.69	$200
3	Growing Media	7	Ton	$107.10	$800
4	3/8" stone (#8)	11	Ton	$72.13	$800
5	filter fabric	160	SF	$3.00	$500
6	Perforated 4" PVC Pipe (Underdrain)	160	LF	$5.10	$1,200
7	Native Plants	20	EA	$45.46	$1,000
8	4" Diameter Solid Wall PVC (Overflow)	4	LF	$4.93	$200
9	CMU Concrete Block Wall	368	SF	$8.78	$4,100
10	4" Diameter Solid Wall PVC (Outflow)	10	LF	$8.65	$100
11	Interpretative Sign	2	EA	$1,372.05	$2,800
			Subtotal		**$9,200**
			Engineering (15%)		**$1,380**
			Mobilization (5%)		**$460**
			Permits and Insurance (5%)		**$460**
			Subtotal		**$11,500**
			Contingency (20%)		**$2,300**
			Total		**$13,800**

*Note: Although the cost estimate is performed in order to calculate the unit cost for one planter, there is only intended to be two interpretive signs installed for all of the planters installed. For the purpose of this project, the total cost for the signage was divided by the number of intended installed planters (14), and was added to the remaining line items. The entire cost of the sign is accounted for in the total cost for the 14 planters.

Appendix H: Annual Maintenance Costs

Table G-1: Annual Maintenance Costs for the BMP and the Add-on Element

BMP	sq ft per Unit	Unit	Total sq ft	Cost per sq ft	Total
Bioretention Basin	3071	1	3071	$2.50	$7,700
Pervious Pavement	11000	1	11000	$0.24	$2,700
StormTree Islands	442	14	6188	$2.50	$15,500
Dry Enhanced Swale	1240	1	1240	$0.86	$1,100
Planters	160	16	2560	$0.80	$2,100

In the GCSMM, maintenance unit costs are provided for some of the BMP's (GCSMM, 2020, vol 2). The Sustainable Technologies Evaluation Program (STEP) was used to find the remaining maintenance costs by taking an average of the sum of minimum costs and sum of maximum costs for the maintenance tasks, which are shown in Figure G-1 (TRCA, 2018). If a BMP had a unit cost from both the GCSMM and STEP, the larger value was used to calculate the total annual maintenance cost.

Bioretention	Costs per m² of BMP area	
Tasks	Min.	High
Watering - first year only	$3.67	$3.67
Watering - second year only	$1.24	$1.51
Annual watering - Starts in year 3	$0.37	$0.73
Drought watering	$0.19	$0.19
Remove litter and debris	$0.33	$0.63
Prune shrubs or trees	$0.45	$0.45
Weeding	$0.31	$0.61
Sediment removal - starts year 2	$1.36	$2.71
Add mulch to maintain 5 to 10 cm - starts year 2	$3.77	$3.77
Replace dead plantings - starts year 2	$3.35	$6.69
Flush sub-drain - starts year 2	$0.59	$0.59
Rehabilitation (every 25 years)	$59.46	$59.46

Enhanced Swales	Costs per m² of BMP area	
Tasks	Min.	High
Watering - First year only	$6.43	$6.43
Watering - Second year only	$2.17	$2.64
Annual watering - Starts in year 3	$0.64	$1.29
Drought watering	$0.34	$0.34
Remove litter and debris	$0.33	$0.63
Mowing	$0.56	$1.12
Core aeration	$0.84	$0.84
Weeding	$0.54	$1.07
Pruning	$0.78	$0.78
Remove sediment - Starts in year 2	$0.90	$1.81
Replace sod - starts year 2	$0.35	$0.70

Permeable Pavement	Costs per m² of BMP area	
Tasks	Min.	High
Remove litter	$0.33	$0.63
Surface vacuum - Starts year 2	$0.40	$0.80
Restriping	$0.46	$0.46
Replace pavers	$0.50	$1.00
Clean out pipes	$0.04	$0.04
Re-place joint material after vacuuming	$0.18	$0.36
Rehabilitation	$76.55	$76.55

Figure G-1: BMP Maintenance Tasks and Costs (TRCA, 2018)