Analysis of Bioretention Basin Infiltration and Stormwater Runoff for Chambersburg Borough, Franklin County, Pennsylvania

By

Molly Eck

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Faculty Advisor: Dr. Christopher Woltemade

Abstract

Bioretention has become one of the most frequently used Best Management Practices (BMPs) to address stormwater runoff in urbanized watersheds. Rhodes Drive, located in Chambersburg Borough, Franklin County, Pennsylvania is the proposed location of a bioretention facility, which will disconnect the direct delivery of stormwater from Rhodes Drive and the surrounding area to Falling Spring Creek, and provide stormwater management prior to being discharged during events in which the proposed bioretention basin would overflow. Data gathered from the Borough including a field report on soil properties, the project plan created by ARRO Consulting, Inc., contributing basin topography, as well as storm sewer maps were utilized using ArcMap as well as TR-55 software. The infiltration rate at three study sites located within the future bioretention basin site was measured using a double-ring infiltrometer, and averaged to result in one average rate for the basin. TR-55 stormwater modeling software was applied to estimate variables such as runoff volume and peak rate of discharge. The efficiency of the basin in regards to the volume of runoff expected was analyzed based off of percent infiltration vs. overflow across a range of design storm events. Results of the study included 57 to 99.4 percent of runoff volume being infiltrated by the basin over a range of design 24-hour storm events, which would have otherwise been delivered directly to Falling Spring Creek. Such results indicate the successful effects the bioretention basin will have on the Falling Spring Creek sub-watershed.

Table of Contents

Figures and Tables

1.0. Introduction

Stormwater management strategies have evolved significantly over the past few decades. The Pennsylvania Stormwater Management Act of 1978, amended in 2002, requires counties within designated watersheds to develop a stormwater management plan using six Minimum Control Measures (MCM) to limit the impacts of stormwater runoff (StormwaterPA 2012). Required within each of the six MCMs are Best Management Practices (BMPs) which work to treat stormwater runoff from urban areas.

The Borough of Chambersburg is unique among Pennsylvania municipalities. Although many large cities have already established a municipal separate storm sewer system (MS4) utility, Chambersburg is one of the first smaller municipalities in Pennsylvania to do so. This utility exists to manage the infrastructure, rules, policies, local laws, and environmental responsibilities of the Borough's storm sewer system (Borough of Chambersburg 2016). It also complies with the requirements of the MS4 National Pollutant Discharge Elimination System (NPDES) permit pursuant to the Clean Water Act, in which the ultimate goal is to improve water quality and groundwater recharge through education, coordination, development, maintenance, and BMPs (US Environmental Protection Agency (EPA) 2016). A recent BMP which has gained significant attention in the past decade is the bioretention system.

1.1. Rhodes Drive Stormwater Improvements Project

The Borough of Chambersburg, under head supervision of their storm sewer system manager, Andrew Stottlemyer, is currently in the process of starting a stormwater improvements project on Rhodes Drive; a 24-foot-wide roadway with two existing storm inlets that discharge directly to the Falling Spring Creek. The scope of the project includes the following:

1. Construction of a bioretention basin that will disconnect direct delivery of stormwater via piped flow from Rhodes Drive and surrounding properties from the Falling Spring Creek, as well as provided stormwater management prior to being discharged

2. The removal of the existing sidewalk along Rhodes Drive and construction of a new pervious sidewalk/nature trail that will meander through the grassed area adjacent to the stream

3. The reconstruction of Rhodes Drive, reducing the 24-foot-wide road to a 20-foot-wide roadway

Although the Borough has multiple goals involving different types of construction, pre-development infiltration testing in the location of the bioretention basin is the main focus of this research, as well as TR-55 stormwater modeling calculations and assessment of the volumetric function of the basin.

2.0. Bioretention and Infiltration Background

Urbanization leads to an increase in impervious land cover which typically slows rainfall infiltration, altering site hydrology, and degrades water quantity and quality (Endreny and Collins 2009). As a result, Low Impact Design/Development (LID) has been introduced as a sustainable method for watershed development and restoration with the goal of mimicking pre-development hydrology. One example of a stormwater LID is the bioretention basin.

2.1. Bioretention basin design and purpose

Bioretention is designed with the goal of minimizing surface water runoff volume (Morzaria-Luna et al. 2004). The construction and upkeep of bioretention basins has multiple purposes such

as filtering pollutants, recharging groundwater by infiltration, reducing stormwater temperature impacts, enhancing evapotranspiration and aesthetics, as well as providing habitat (PA-DEP 2004).

According to Roy-Poirier et al. (2010), these systems consist of small areas which are excavated and backfilled with a mixture of high-permeability soil and organic matter designed to maximize infiltration and vegetative growth. A ponding area serves as reserve space for runoff storage and provides additional time for water to infiltrate into the media (Hsieh and Davis 2005). An important factor in the design of these structures is the covering of native terrestrial vegetation, which is selected due to its resistance of environmental stresses. Many studies have proven the effects of water availability for biological roles (Bohnert et al. 1995), explaining why the selection of vegetation is important for the design and efficiency of bioretention basins.

A review of the guidelines for bioretention design indicates five main sizing methods (Roy-Poirier et al. 2010). The states of Georgia, Maryland, New York, and Vermont require that bioretention facilities be sized based on a volume of runoff to be treated to meet water quality objectives, where the filter bed sizing is based on Darcy's law. Guidelines for the states of Virginia and Idaho require that bioretention areas cover a specific percentage of the total impervious drainage area, and the state of Delaware requires the layout to meet volumetric loading rates. Pennsylvania is very flexible with sizing and target infiltration rate of its bioretention facilities. Typically, the size of the basin is dependent on the amount of runoff it needs to contain with no specific identification of goals regarding to percentage of runoff infiltrated, water quality improvement, etc.

In addition to reducing runoff by ways of infiltration, the design of bioretention basins involves multiple mechanisms for pollutant removal such as filtration, adsorption, and possibly biological treatment (Davis et al. 2009). Many studies have been performed on determining the efficiency of

bioretention basins in regards to contaminant removal such as the study by Birch et al. (2005) where the weighted average concentration of total suspended solids in the stormwater was reduced by an average of 50 percent.

Similar studies assess the ratio of inflow into the bioretention basin vs outflow, instead of pollutant loads (Hunt et al. 2006) which is encompassed in this research. The efficiency of bioretention basins has been studied by scientists like Li et al. (2009) who investigated the hydrologic performance of six bioretention basins in Maryland and North Carolina. Outflow from each cell was recorded and inflow was either recorded or calculated from rainfall data. Results indicated that bioretention basins can achieve substantial hydrologic benefits through delaying and reducing peak flows and decreasing runoff volume (Li et al. 2009).

Other studies have evaluated the hydraulic retention performance of infiltration basins in the long-term such as the research presented by Dechesne et al.(2004) on indicators for hydraulic and pollution retention assessment of stormwater infiltration basins. In this study, performance indicators were developed to assess aspects of basin performance such as drainage duration, overflow frequency, particle filtration, pollution trapping, etc. (Dechesne et al. 2004). Methods of evaluation included field investigation and long-term simulation modeling. They determined that such hydraulic indicators are reliable and their evaluation is representative of basin behavior.

2.2. Infiltration in a bioretention facility

Infiltration is an important soil process that controls leaching, runoff, and water availability (Franzluebbers 2002). A series of experiments was performed to study the infiltration behavior of bioretention systems over long time periods. In a study by Le Coustumer et al. (2007), hydraulic conductivity of the soil media was found to decrease significantly over the first four weeks of the experiment, after which it leaned toward a constant value. Likewise, over 49 storm events were

evaluated between two bioretention facilities installed at the University of Maryland which demonstrated that bioretention can effectively reduce the impacts of development on hydrologic regimes in urban areas (Davis 2008). In fact, all stormwater from small rain events recorded in the Davis (2008) study was captured by the bioretention basins.

2.2.1. Infiltration measurement

Measuring infiltration can help improve stormwater management, and guide proper implementation of BMPs. The ring infiltrometer method allows for appropriate sampling strategies, and is a preferred method amongst hydrologists. Factors tested using this method include the soil water content at the beginning of the experiment, the height from which water is poured onto the soil surface, and the duration of the infiltration test (Alagna et al. 2016).

Johnson (1963) explains how Burgy and Luthin (1956) concluded that six infiltrometers, used in a uniform soil profile having no layers restricting the movement of water, gave an average rate that was within 30 percent of the true mean when compared with rates obtained by flooding large areas or basins. This means that for the infiltration testing to be truly accurate, the location of the tests should be based on the geology or soil pattern of an area. It is important to note that most of the investigations of infiltrometer rings have been made by scientists interested in the evaluation of agricultural soils. Therefore, these infiltration rates were determined from the upper layers of the soil profile, not subsoil infiltration in the bottom of a bioretention basin.

3.0. Purpose

This research examines the volumetric design and function of a proposed bioretention basin in relation to modeled precipitation storm events resulting in runoff towards Rhodes Drive in Chambersburg Borough.

3.1. Research Questions

1. How much runoff does the study site currently produce under a range of storm magnitudes, and how will the implementation of the bioretention basin alter that?

2. What percentage of total runoff volume will be captured and infiltrated by the bioretention basin across a range of design storms?

4.0. Study Area

The Borough of Chambersburg is located in the South Central region of Pennsylvania (Figure 1), 13 miles north of the Maryland border and 52 miles southwest of Harrisburg. Located in Franklin County, the Borough encompasses roughly 6.9 square miles and has a population of approximately 20,000 people according to the 2010 census (United States Census Bureau 2015). Chambersburg has a temperate climate with warm summers and cold winters, and receives an average of 41 inches of precipitation per year (United States Climate Data 2016). Land use in the Borough is highly urbanized; including residential, commercial, and manufacturing use.

The study site for this research is located in the Falling Spring Creek sub-watershed of the Potomac watershed along Rhodes Drive, adjacent to the Coyle Free Library, residential units at the Tower at Falling Spring, and the King Street Church Parking lot. Rhodes Drive plays a significant role in providing emergency access for the Chambersburg Fire Department. Located

along 130 North Second Street, the Chambersburg Fire Department utilizes a direct route (via Rhodes Drive) to respond to any emergencies that occur on the south side of the Borough. Rhodes Drive is a 24-foot-wide roadway with two existing storm inlets that discharge via a single pipe directly to the Falling Spring Creek.
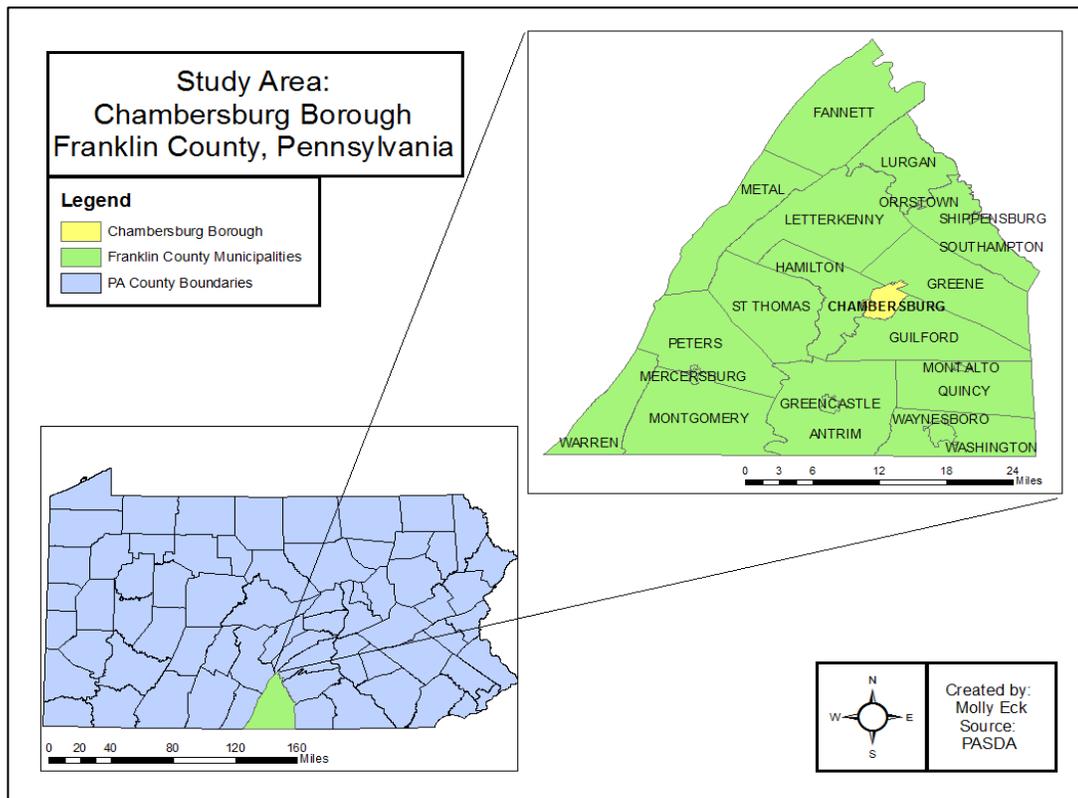
Figure 1. The Chambersburg, Pennsylvania Study Area (Source: Eck 2016)

4.1. Geology

The Borough of Chambersburg lies within the Great Valley Section of the Ridge and Valley Physiographic Province of Pennsylvania which consists of a very broad lowland with the rock types eroded into the hills on the north side, and an even flatter landscape developed on limestones and dolomites on the south side (PA DCNR 2016). Limestone lithology underlies the entire study site within the research, and the Borough of Chambersburg is no stranger to the impacts of such

lithology on the hydrologic system. This landscape is a challenge when it comes to stormwater management. It brings into question the efficiency of BMPs being implemented in such terrain due to the high probability of sinkhole development and potential water quality issues. The goal for stormwater BMPs in carbonate areas is to distribute infiltration and not concentrate runoff (PA DEP 2004).

4.2. Soils

The study area consists of all soils underlying urban land with three percent slopes (USDA Web Soil Survey 2013). Due to the high amount of urban land cover, soil data from the USDA Web Soil Survey (2013) was not useful for this analysis. Instead, field reports by ARRO Consulting Inc. (Biannaras 2016) were used to give a better idea of the variability in soil profiles throughout the study area. Three test pits were dug and visually assessed. Results from each test pit are displayed in Table 1. A ribbon test performed in test pit one resulted in a one-inch ribbon, indicating little clay content. A small root system was encountered at the organic layer, as well as concrete sidewalk and existing pipe. The ribbon test performed at test pit two resulted in a three-inch ribbon indicating higher clay content than pit one. The ribbon test performed in test pit three developed a 3.75-inch ribbon indicating an even higher clay content than test pit two. Also, the clay they tested here was mildly saturated, and concrete sidewalk, foundation, and bricks were unearthed indicating previous land-altering activity.

Land disturbance in the study area is the main reason for the substantial variation across the three soil profiles, which could lead to significantly different infiltration rates. Infiltration rate is dependent on soil texture (percentage of sand, silt and clay) and clay mineralogy (USDA 2008) due to the increase of water movement through large pore spaces in a sandy soil versus small pores of soil with high clay content.

Table 1. Soil Profile Descriptions of the Rhodes Drive test pits (Source: Biannaras 2016)

Pit Depth	Soil Profile Description
Test Pit One	
0" to 10"	Gray; coarse sand; distinct red streaks; abrupt smooth boundary
10" to 18"	Reddish brown; coarse sandy clay; distinct red streaks; abrupt smooth boundary
18" to 48"	Brownish clay; coarse sandy clay; abrupt smooth boundary
Test Pit Two	
0" to 5"	Brown; clay, sandy; faint pink/white streaks; abrupt smooth boundary
5" to 9"	Existing road (asphalt) and gray fly ash debris
9" to 17"	Black; clay loam; faint gray streaks; abrupt smooth boundary
17" to 42" +	Brown; firm clay, fine; light brown and red streaks; abrupt smooth boundary
Test Pit Three	
0" to 14"	Black; sand, coarse; distinct red streaks; abrupt smooth boundary
14" to 26"	Brown with red hue; sandy clay; distinct red streaks; abrupt smooth boundary
26" to 30"	Gray/white; sand/fly ash; distinct black streaks; abrupt smooth boundary
30" to 54"	Brown/black; fine clay; abrupt smooth boundary

5.0. Methods

The main objective of this research was to perform pre-construction infiltration testing at the Rhodes Drive bioretention site for Chambersburg Borough. TR-55 stormwater modeling procedures were applied to estimate stormwater runoff volumes in the study area for a range of storm events, and analyzed in line with the project design/dimensions to determine the volumetric function of the basin.

5.1. *Secondary data*

Documentation such as the Rhodes Drive Field report (Biannaras 2016) provided by the Borough of Chambersburg was used to characterize soil properties at the study site. A storm sewer system map (Borough of Chambersburg GIS Data 2016) was also utilized to display the location of the storm sewer inlets and outfalls within the study site. The plan for the Rhodes Drive Bioretention BMP (Arro Consulting, Inc. 2016), was used to interpret the design and dimensional details of the project, and contributing basin contour information (Borough of Chambersburg GIS

Data 2016) was used to create a contributing watershed boundary map which was field checked to confirm accuracy.

5.2. Primary data collection

Three test pits were dug 48 inches below the surface within the proposed bioretention site by employees of the Public Works department of Chambersburg Borough on the day of the tests. The equilibrium saturated infiltration rate was tested at three pit sites with a Turf-Tec double-ring infiltrometer at the base of each pit. The infiltrometers' inner ring had a diameter of six inches, outer diameter of 12 inches, and was four inches tall with an additional two inches in the ground. While recording the time, water was added to the inner and annular ring of the infiltrometer to maintain a constant head of two inches until the infiltration rate was constant over a 30-minute period with no more than a 10 percent variation in readings. The volume of liquid that was added to maintain a constant head in the inner ring and annular space was recorded in a field notebook.

The final infiltration rate was calculated by determining the mean rate for the inner ring over the final 30 minutes of the test for each pit. The three rates were then averaged to get a mean infiltration rate for the entire bioretention basin. Contributing basin contour information and field observations were used to delineate the watershed currently supplying stormwater runoff to the Falling Spring Creek, and ultimately after construction, the bioretention basin (Figure 2). After the watershed boundary was defined, traits such as area, length, and CN value were established to be incorporated into TR-55 modeling. In order to determine the average CN value for the watershed, the NRCS table (Table 2) providing runoff curve numbers for urban areas was used (NRCS 2004).

Table 2. NRCS CN delineation (Source: NRCS 2004)

Cover description		Curve numbers for hydrologic soil group			
Cover type and hydrologic condition	Average percent impervious area [2]	A	B	C	D
Fully developed urban areas (vegetation established)					
Open space (lawns, parks, golf courses, cemeteries, etc.) [3]:					
Poor condition (grass cover < 50%)		68	79	86	89
Fair condition (grass cover 50% to 75%)		49	69	79	84
Good condition (grass cover > 75%)		39	61	74	80
Impervious areas:					
Paved parking lots, roofs, driveways, etc.					
(excluding right-of-way).....................................		98	98	98	98
Streets and roads:					
Paved; curbs and storm sewers (excluding					
right-of-way)		98	98	98	98
Paved; open ditches (including right-of-way)............		83	89	92	93
Gravel (including right-of-way)		76	85	89	91
Dirt (including right-of-way)		72	82	87	89
Western desert urban areas:					
Natural desert landscaping (pervious areas only) [4]		63	77	85	88
Artificial desert landscaping (impervious weed barrier,					
desert shrub with 1- to 2-inch sand or gravel mulch					
and basin borders)		96	96	96	96
Urban districts:					
Commercial and business	85	89	92	94	95
Industrial	72	81	88	91	93
Residential districts by average lot size:					
1/8 acre or less (town houses)	65	77	85	90	92
1/4 acre	38	61	75	83	87
1/3 acre	30	57	72	81	86
1/2 acre	25	54	70	80	85
1 acre	20	51	68	79	84
2 acres...	12	46	65	77	82
Developing urban areas					
Newly graded areas					
(pervious areas only, no vegetation) [5]........................		77	86	91	94

The implementation of the United States Department of Agriculture (USDA) TR-55 stormwater modeling software provided storm runoff volumes, peak rate of discharge, hydrographs, and storage volumes required for 100% retention in the bioretention basin (USDA 1986). Calculations were made using the TR-55 curve number method for 1-, 2-, 5-, 10-, 25-, 50-, and 100-year, 24-hour storm events. These data were evaluated in conjunction with the bioretention basin design in order to indicate the range of events for which 100%

retention/infiltration was achieved as well as the amount of overflow that would occur in larger events.
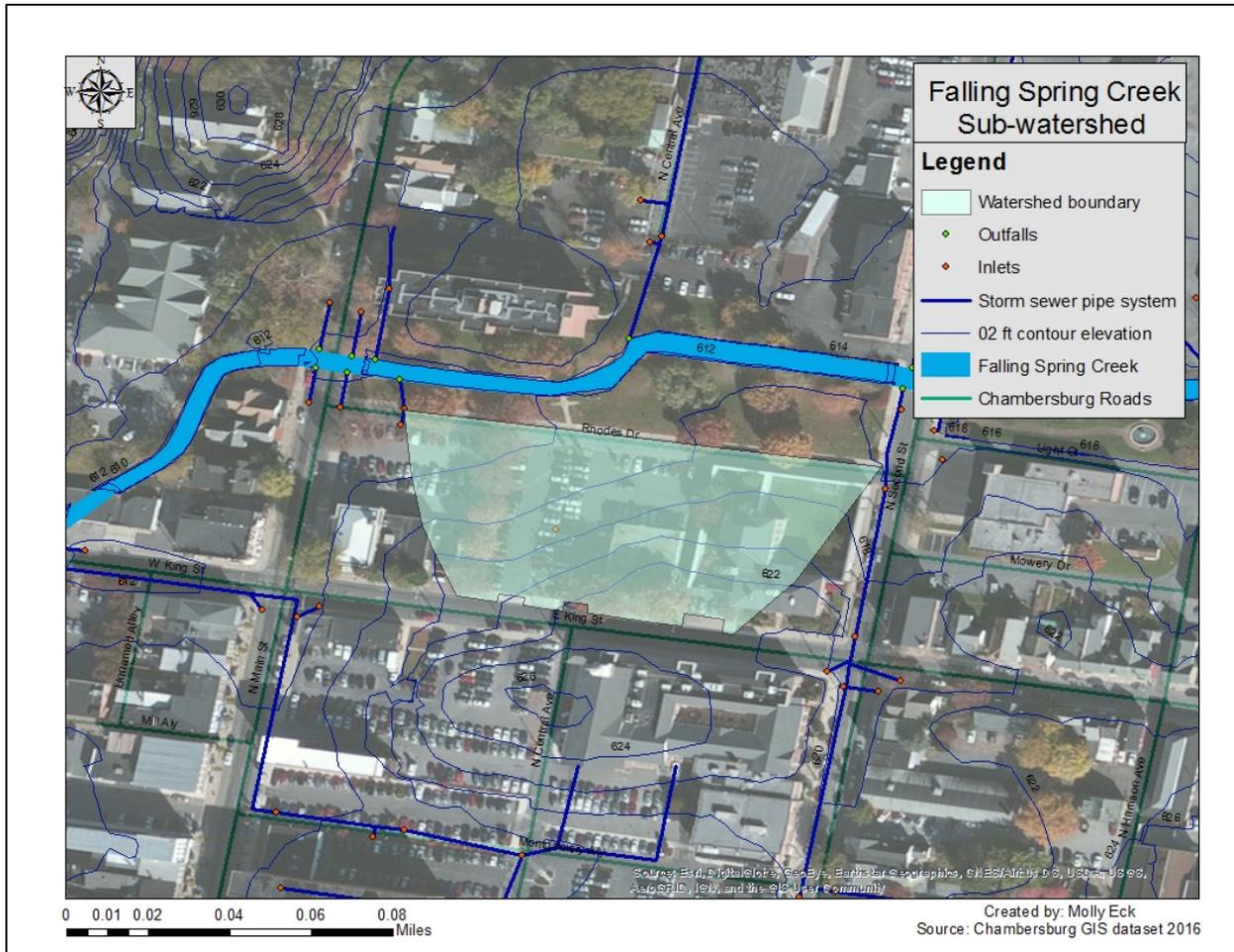
Figure 2. Falling Spring Creek Sub-watershed map (Source: Borough of Chambersburg GIS Data 2016)

5.3. Analysis

Using the infiltrometer testing results, the mean infiltration rates over the final 30 minutes of the test for each pit were determined and averaged to develop a mean infiltration rate for the entire bioretention basin. Characteristics of the drainage area created from contour data provided in the Borough of Chambersburg's GIS dataset (2016) were used in the TR-55 procedure to

determine the amount of runoff being introduced to the bioretention basin and into Falling Spring Creek.

In order to determine the size storm event that would result in full capacity of the bioretention basin, as well as potential overflow, data from the TR-55 modeling were analyzed using a variety of storm events, including the 1-, 2-, 5-, 10-, 50-, and 100-year 24-hour storm events.

6.0. Results and Discussion

In order to determine the overall volumetric function of the proposed Rhodes Drive bioretention basin, results from the infiltration testing were considered along with characteristics of the Falling Spring Creek sub-watershed and results from the TR-55 modeling.

6.1. Infiltration testing

As expected, considerable variation of infiltration rates occurred between the three test pits (Figure 3). The average infiltration rate occurring within the final 30 minutes of each test when the soil was completely saturated were 1.55 in/hour for test pit one, 4.23 in/hour for test pit two, and 4.55 in/hour for test pit three. A substantial amount of land disturbance was observed in each pit, as well as significant amounts of variation in each soil profile. Pit one appeared to be closer to the water table than the other two test pits, leading to a higher antecedent moisture content and therefore a lower infiltration rate. The average of the three infiltration tests was computed as 0.29 ft/hour or 1,252.8 ft^3/hour, and used as the mean infiltration rate for the bioretention basin.

Due to the quantitative uncertainty of the infiltration rate by the highly variable soil conditions across the site with varied historical urban impacts, combined with basing the mean

rate on only three test sites, a worst-case scenario infiltration rate was calculated. The average lowest infiltration rate encountered at the study site was 0.21 ft/hour or 907.2 ft^3/hour.
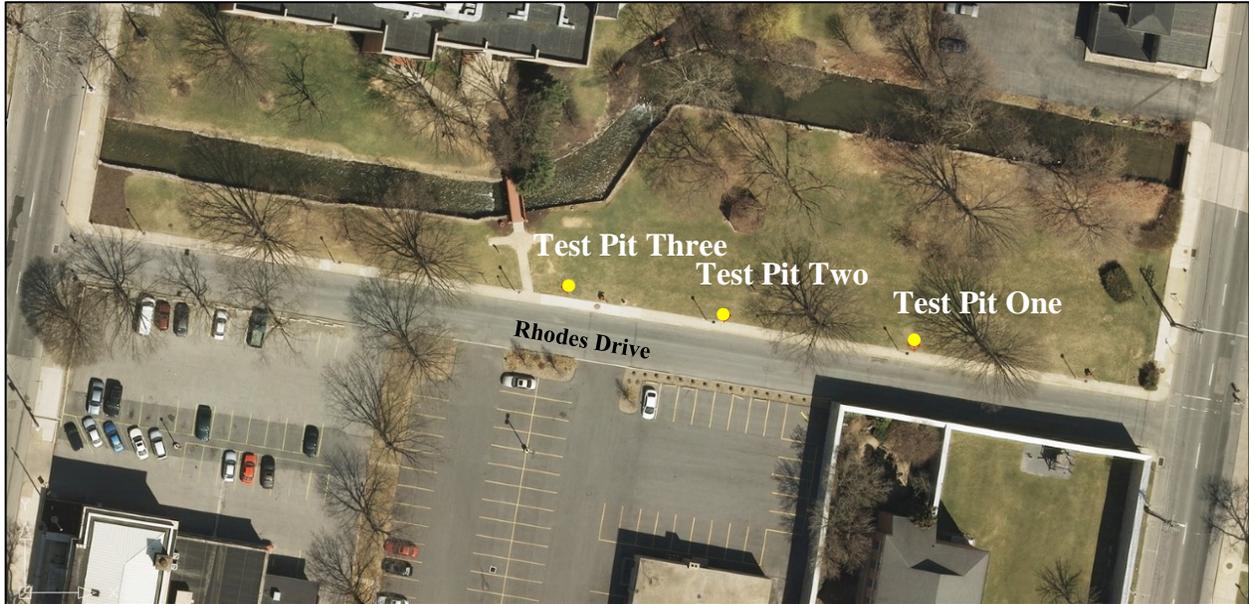
Figure 3. Rhodes Drive Infiltration Test Pit Sites (Source: Stottlemyer 2016)

6.2. TR-55 results

Precipitation frequency data from the NOAA Chambersburg station (NOAA/NWS 2014) was entered into TR-55 as the Type II rainfall distribution. The weighted CN was 95 which is descriptive of an area with a high percentage of impervious surfaces and HSG D soils (NRCS 2004)

Table 3. Falling Spring Creek Watershed Characteristics

Watershed characteristics
Length: 233 ft
Slope: 0.03
Area: 2.10 acres or 91,476 ft^2
Average CN (D soils): 95 (If C soils: 94)
Manning's roughness coefficient (n): 0.011
Tc: 0.05 hr (used default of 0.10)

which were used as the worst case scenario due to the uncertainty of HSG at the study site. The time of concentration (Tc) was calculated through TR-55 by inserting features of the watershed, displayed in Table 3, including the sheet length, slope, and the appropriate Manning's roughness coefficient. Although the actual calculation resulted in a Tc of 0.05 hr, 0.10 hr is the minimum Tc

in TR-55 and was used as default for this research. The last input needed for TR-55 was the watershed area of 2.10 acres.

The TR-55 model was run for the 1-, 2-, 5-, 10-, 25-, 50-, and 100- year storm events, resulting in runoff amounts, as well as peak flow rates and runoff volumes as seen in Table 4. In order to determine how functional the proposed bioretention basin would be in terms of percent infiltration versus percent overflow, it was important to determine the amount of runoff currently flowing into Falling Spring Creek before construction of the bioretention basin begins. Results from TR-55 of current runoff volumes flowing into Falling Spring Creek allowed for comparison after the bioretention basin attributes were incorporated.

Table 4. TR-55 results for each design storm event (Source: USDA 1986)

Storm event	Precipitation (in)	Runoff amount (in)	Runoff amount (ft)	Peak flow rate (cfs)	Runoff volume (ft^3)
1-year	2.45	1.87	0.16	5.93	14,636
2-year	2.94	2.35	0.20	7.31	18,295
5-year	3.66	3.06	0.26	9.32	23,784
10-year	4.27	3.67	0.31	11.02	28,358
25-year	5.18	4.57	0.38	13.54	34,761
50-year	5.98	5.37	0.45	15.73	41,164
100-year	6.88	6.27	0.52	18.20	47,567

6.3. Basin design storage depth and volume

The basin design storage depth was calculated from the design of the bioretention basin and fill material. As shown in Figure 4, the first layer of fill will be 12 inches of clean gravel, followed by 18 inches of amended soils, and 4 to 6 inches of clean river gravel on top. The maximum ponding depth for the
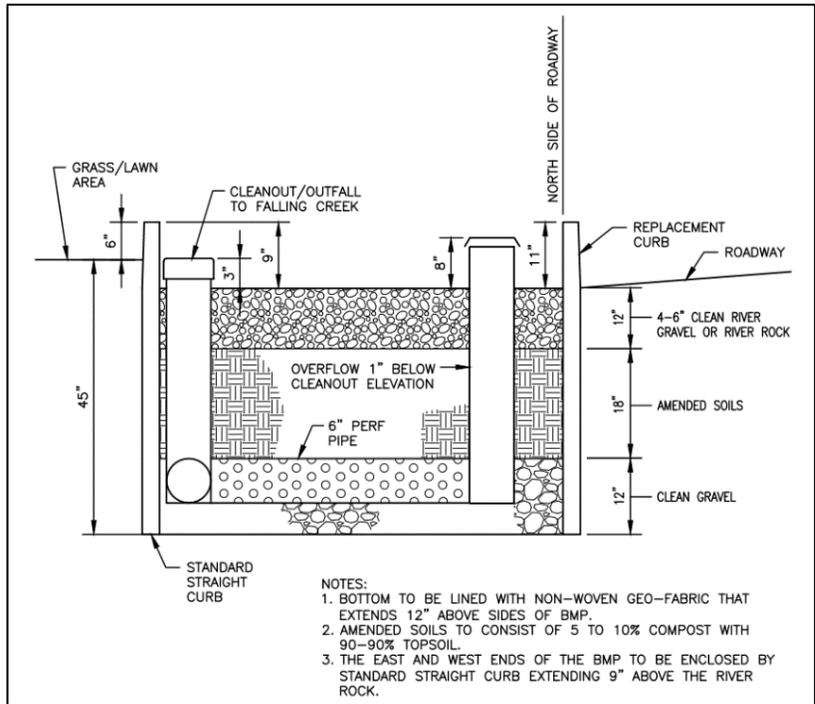
Figure 4. Fill material and dimensions of the Rhodes Drive BMP (Source: Arro Consulting, Inc. 2016)

basin is 3 inches. In order to calculate the storage depth of the basin, porosity values were needed for each fill type.

As seen in Table 5, the accepted porosity for each material (Virginia DCR 2013) was multiplied by the depth and added together to calculate the total storage depth of 17.10 inches or 1.42 ft for the bioretention basin.

The storage volume of the basin was determined by multiplying the width of 8 ft by the storage depth of 1.42 ft, and length of 540 ft, resulting in a total storage volume of 6,177.60 ft^3. This value is the maximum capacity of the bioretention basin, therefore any runoff volumes above that value, except what infiltrates, will result in overflow.

Table 5. Calculation of basin design storage depth (Source: Virginia DCR 2013)

Basin design storage depth	Porosity values
Soil media: 18 in or 1.5 ft	0.25
Gravel: 24 in or 2 ft	0.40
Max. ponding depth: 3 in or 0.25ft	1.00
(1.5ft * 0.25) + (2.0ft * 0.40) + (0.25ft * 1.00) = **1.42 ft or 17.10 in**	

6.4. Functionality of the bioretention basin

After establishing the characteristics of the watershed and the bioretention basin, the runoff volume, total infiltration, excess, storage volume, and overflow quantities were computed and input into an hourly water budget for each storm event to determine the functionality of the basin. Results from the water budget found in Table 6 display not only runoff and overflow volumes for each design storm event, but the large amounts of water that could be infiltrated by the basin, which otherwise would have been included as runoff. The table also displays percentages of infiltration versus overflow.

In a 1-year storm event, which would produce 2.45 inches of rain in 24 hours, 99.4% of the total runoff volume could be infiltrated by the bioretention basin. In a 100-year storm event, which would produce 6.88 inches of rain in 24 hours, the basin could infiltrate 57% of the runoff volume the storm would produce. These results demonstrate the benefits the basin will have on the Falling Spring Creek sub-watershed. In fact, the percentage of infiltration was much higher than the percentage of overflow for each storm event. The introduction of the bioretention basin to this urban hydrologic system will allow for a decrease of roughly 14,448 cubic feet of stormwater runoff resulting from a 1-year precipitation event, compared to a decrease of nearly 27,418 cubic feet of runoff resulting from a 100-year precipitation event through infiltration.

Table 6. Hourly water budget calculations for each design storm event (Source: Eck 2016)

Storm event	Total Runoff Volume (ft^3)	Total Infiltration (ft^3)	Total overflow (ft^3)	% Runoff being infiltrated	% Overflow
1-year	14,544.0	14,448.12	95.88	99.4	0.6
2-year	17,928.0	15,775.20	2,152.80	88	12
5-year	23,868.0	18,288.00	5,580.00	77	23
10-year	28,296.0	20,160.00	8,136.0	71	29
25-year	35,136.0	22,780.80	12,355.20	65	35
50-year	41,508.0	24,904.80	16,603.20	60	40
100-year	48,096.0	27,417.60	20,678.40	57	43

7.0. Conclusions

The main purpose of this research was to determine the overall volumetric function of the Rhodes Drive BMP being constructed by Chambersburg Borough in Spring of 2017. In order to determine this, the TR-55 curve number method was used to compute stormwater runoff volumes that would flow towards the bioretention basin. These runoff values combined with the project design drafted by Arro Consulting, Inc., led to the assessment of the bioretention basin in terms of percent infiltration versus percent overflow.

The average infiltration rate of the Rhodes Drive bioretention basin will result in the infiltration of 57 to 99.4 percent of the total runoff volume generated by a range of storm events; depending on the storms' magnitude and frequency. However, given that the infiltration rates were averaged from only three sites with non-uniform soil characteristics, it is important to note the possibility of 30 percent error with these estimates. Regardless, the infiltration of stormwater in the bioretention basin will lead to low volumes of overflow, and proves the basin will be effective

in meeting the Borough's goal of reducing the amount of stormwater runoff entering the Falling Spring Creek.

Although this research only pertains to the design and productivity of the bioretention basin, it is important to note that the overall project encompasses other means of reducing runoff, including a pervious sidewalk parallel to the basin. Therefore, the actual volume of runoff that would enter the Falling Spring Creek may be even less than projected by this study.

This research not only presents the benefits of constructing a bioretention basin for this site, but also suggests that these Low-Impact Development BMPs could likely be implemented effectively in other highly urbanized areas.

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