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Analysis of LID Implementation to Combat Flooding and Erosion at the University of Arkansas Campus

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LID Implementation to combat downstream erosion and flooding on the University of Arkansas Campus

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College of Engineering

University of Arkansas

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Contents

Abstract

The city of Fayetteville, Arkansas has experienced rapid urbanization throughout recent years as it continues to grow. Within the city, the University of Arkansas has been constantly expanding, with increased impervious surfaces as more parking lots and facilities are built. This has caused issues including flooding and streambank erosion, specifically in Mullins Creek, which receives runoff from a large part of campus. A portion of the creek was restored, but there are still downstream issues. Low Impact Development (LID) is a type of green infrastructure that has been shown to decrease runoff and increase infiltration. EPA SWMM, a hydrologic modeling software, was used to analyze the effectiveness of implementing LID at Lot 56, adjacent to Mullins Creek. Two layouts were developed: the condensed layout with 5 bioretention cells, and the dispersed layout with 29 cells. The results for both layouts showed significant decrease in runoff and increase in infiltration. With the ideology of Volume Based Hydrology, it can be assumed that the decrease in runoff will also cause a decrease in pollutant loads, and a decrease in erosion and flooding downstream. The implementation of LID at Lot 56, combined with LID implementation throughout the drainage area, can be an effective way to combat downstream erosion and flooding issues at Mullins Creek.

Introduction

As urban development continues to expand around the globe at an exponential rate, it carries with it detrimental effects to the water supply, a loss of biodiversity, and the degradation of ecological systems (Vogel et al., 2015). By altering the natural hydrology of an area, runoff rates and volumes are increased, and infiltration rates are greatly decreased. Instead of slowly infiltrating and traveling through a landscape, stormwater rushes off of these impervious surfaces and directly into the water supply. While different land uses cause different water quality challenges, many studies have shown that impervious surfaces cause more runoff and pollutant loads than any other type of land use (Rushton, 2001). Runoff from urban land is reported to be the leading cause of impairment to lakes in the United States (Davis, 2008).

Traditional engineering, also called Conventional Development (CD), combats flooding by merely re-routing the large quantity of water straight to the water-body, with the singular goal of transporting stormwater away from the site as quickly as possible. Increased flow rates can cause streambank erosion, and associated increased sediment loads. The stormwater also carries pollutants from the urban landscape, including nutrients, bacteria, and toxic metals. With decreased infiltration rates, groundwater recharge also suffers. Overall ecosystem health is ignored in their design, and they often cause downstream water quality issues (Vogel et al., 2015). This includes many Best Management Practices (BMP's), centralized stormwater management ponds, conveyance piping systems, pond/curb inlet structures, concrete roadside ditches, and curb/gutter infrastructure (Ahiablame et al., 2012).

In recent years, the need for more intelligent planning of urban development has been recognized (Ahiablame et al., 2012). Low Impact Development (LID) is one response to this problem that has become increasingly popular. The natural landscape has built in methods for capturing and treating stormwater. Low Impact Development (LID) strategies seek to decrease the runoff and pollutant loads in urban areas by utilizing natural pathways to address the problem at the source. The goal of LID is to return the area to pre-development conditions, reducing runoff, increasing infiltration, improving groundwater recharge, protecting streams, and enhancing overall water quality. In addition, this can reduce the negative impact on soils, vegetation, and aquatic systems, which maximizes ecosystem services and enhances system resilience (Vogel et al., 2015). LID can effectively maintain and restore the function of urban streams (Vogel et al., 2015). Many times, the construction and maintenance of LID structures can be implemented as cost-effectively as conventional development, making it not only environmentally preferable, but also an affordable solution (Vogel et al., 2015).

Much of the LID technology uses the concept of volume based hydrology (VBH), in which the focus is the management of stormwater volumes, assuming that a reduction in volume will, in itself, solve other problems (Ahiablame et al., 2012). When less water is released from a site, the amount of pollutants it carries will decrease also. By retaining more water at the site and slowing the release, the peak flow rate will also decrease. Problems like erosion and sedimentation are aggravated by increased flows, so a decrease in flow volume will alleviate these problems. In these ways, with the applied concept of VBH, LID implementation can decrease pollutant loading, peak flow rate, erosion, and sedimentation.

The goal of this study is to determine if the implementation of LID technology has the potential to successfully alleviate water quantity and quality issues associated with urbanization at the University of Arkansas campus. As impervious area increases with the growth of the University, so does runoff, flooding, and streambank erosion. For the first stage, I will analyze campus within the West Fork – White River watershed to determine drainage areas of special hydrologic concern. For the second stage, I will analyze a single drainage area to determine key areas within the drainage area. For the third stage, I will analyze LID implementation at a specific location within the drainage area.

Literature review

A bioretention cell is one type of LID that attenuates and treats stormwater runoff (Ahiablame et al., 2012). It is a shallow, vegetated depression that is engineered to collect stormwater from impervious surfaces, and decrease total runoff through infiltration and evapotranspiration (LeFevre et al., 2016). The functions of infiltration and evaporation are integral to the function of bioretention, and were shown to account for up to 74% of the runoff flowing through bioretention systems in a study done by Chapman and Horner (Ahiablame et al., 2012). When correctly designed, bioretention cells can capture the entire inflow volume for small storm events (Ahiablame et al., 2012).

Bioretention is also proven to be effective for pollutant control (LeFevre et al., 2016). While most conventional development focuses on capturing particles with physical processes, bioretention systems can effectively capture dissolved pollutants as well, with processes including phytoremediation and sorption (LeFevre et al., 2016). Studies have proven bioretention to be capable of reducing up to 99% of sediment and nutrient losses (Ahiablame et al., 2012). Additives, such as compost or wood chips, can further improve the retention of pollutants including phosphorous, bacteria, and metals (Vogel et al., 2015).

Many studies have proven the effectiveness of LID implementation. A two year analysis on the implementation of two bioretention cells at the University of Maryland campus determined that bioretention cells can effectively reduce the hydrologic impact of impervious surfaces for at least 50% of all rain events (Davis, 2008). Another study in North Carolina demonstrated that bioretention systems captured 75% of all rainfall events (Ahiablame et al., 2012). The Honda campus in Ontario, Canada, was designed with LID as the primary source of stormwater control. Compared to conventional development, the LID design significantly reduced runoff, by up to 62% for total flow, and up to 79% for peak flow (Campus & Markham, 2015). While LID is generally recognized for its effectiveness during small storm events, the hydrologic model for the Honda campus showed that the system provided quantity control for even the 100 year storm (Campus & Markham, 2015). Many studies have proven the benefits of LID at the micro-scale, but information at the watershed scale is lacking (Peterein et al., 2016).

The cells should be designed to drain within 4-6 hours (Davis, 2008). Underdrains can be implemented to control the flow leaving the cell and prevent long periods of ponded water (LeFevre et al., 2016). Engineered soil is largely sand in order to facilitate infiltration. Native, drought tolerant perennial vegetation, including grasses, shrubs, sedges, and rushes, should be planted (Davis, 2008).

Methods

The site area was modeled using the EPA Storm Water Management Model (SWMM), a hydrologic modeling software. The site area is divided into subcatchments, and routed through a system of pipes and channels to defined outlet points. Using rainfall data, SWMM simulates runoff and infiltration from the designated site for each subcatchment and the system as a whole. Many different site characteristics influence stormwater runoff and infiltration, including soil data, subcatchment area, flow width, imperviousness, and slope, all of which must be determined and entered for each subcatchment in the SWMM model.

The model can use four different methods for determining infiltration values: Horton, Modified, Green-Ampt, and the Curve Number method. Our model employed the Curve Number method. Curve numbers were determined for each individual subcatchment based on land cover and Hydrologic Soil Group (HSG). Soil data was obtained from the Natural Resources Conservation Service (NRCS) interactive GIS maps (NRCS, 2016). Data includes soil properties for the 12 different soil types found in the drainage area and Hydrologic Soil Group (HSG). The underlying soil in the area is mostly HSG B and D.

The drainage area was divided into subcatchments based upon land use and soil type. Stormwater routing information was obtained from the City of Fayetteville's GIS website, including stormwater infrastructure, open channel flow, and streams, which was used for the placement of nodes and junctions in SWMM.

The rainfall data used for the SWMM model was obtained from the NOAA National Weather Service website, using the 24 hour, 50% occurrence for all cases at the Fayetteville Exp. Station. (NOAA, 2014). Storm depths for a 24 hour storm in Fayetteville, Arkansas were obtained from the Fayetteville Drainage Criteria Manual for the 2, 10, and 25 year storms, shown in table 1.

Table 1. Storm depths for Fayetteville, Arkansas

Duration (hours)	2 year (in)	5 year (in)	25 year (in)
24	3.92	4.65	6.27

Hourly storm data was calculated using the percentages and storm depths, and added to a rain gauge in SWMM. The hourly precipitation for all storms is shown in figure 1.

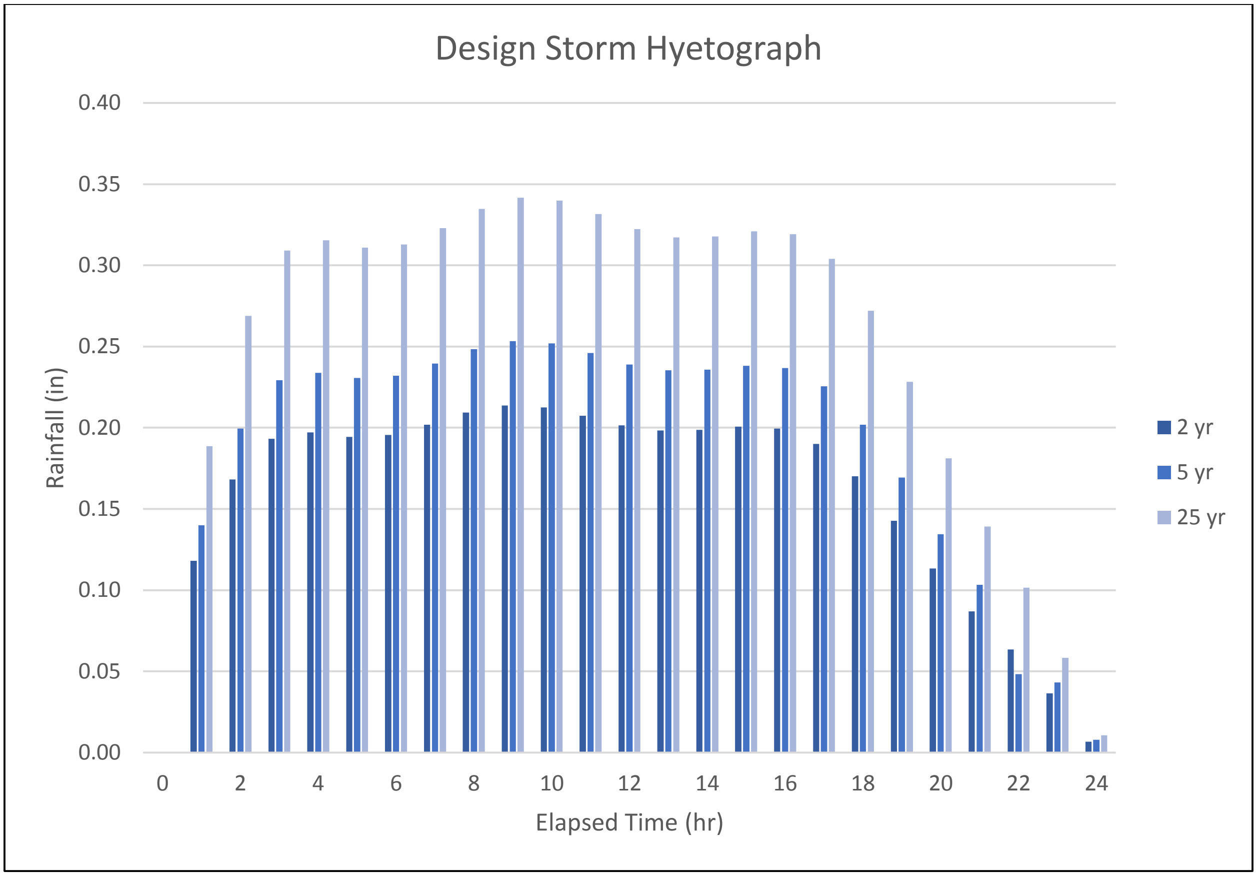

Figure 1: Hyetograph showing hourly rainfall depths for the 24 hour 2, 5, and 25 year design storms.

A map of the slopes was developed from DEM data, obtained from the City of Fayetteville, in ArcGIS, and used to determine average slopes of each subcatchment, shown in figure 2.

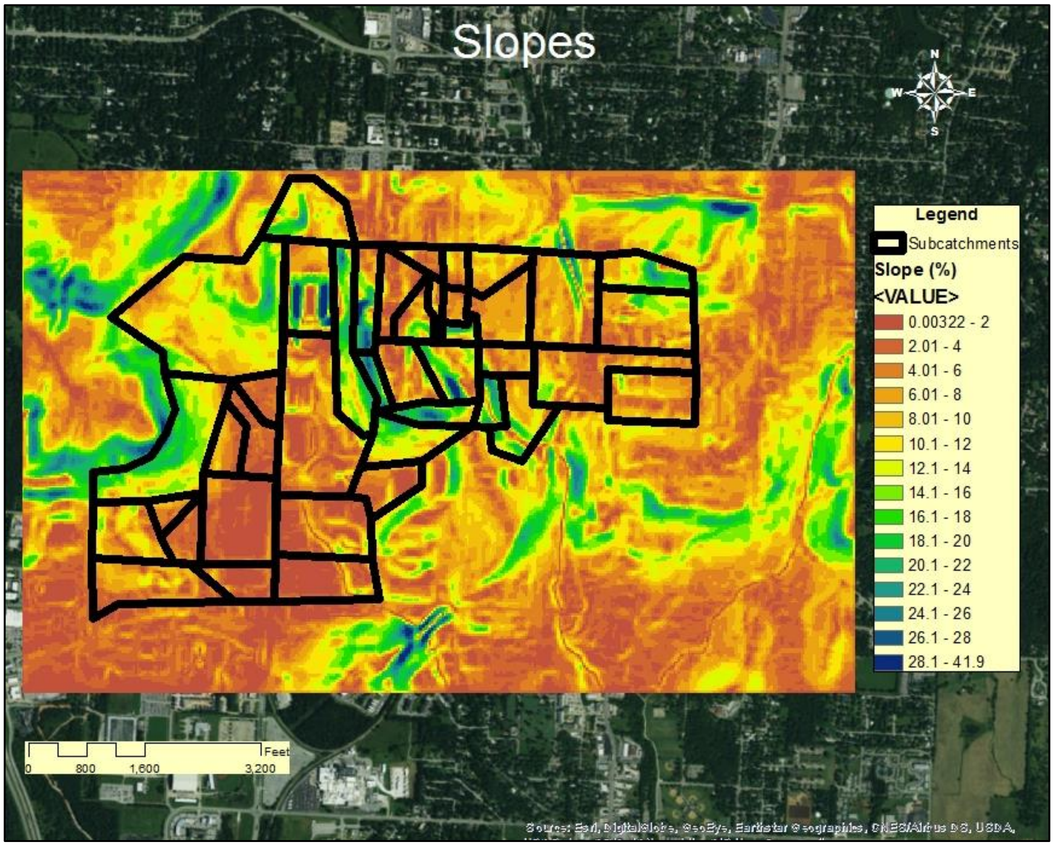

Figure 2: Map of slopes across the drainage area for the West Fork – White River watershed at the University of Arkansas campus; SWMM subcatchments for the drainage area are outlined in black.

Bioretention

SWMM has an LID feature, in which individual LID structures can be implemented and modeled within subcatchments. The capabilities include permeable pavement, rain gardens, green roofs, street planters, rain barrels, infiltration trenches, and vegetative swales.

Bioretention cell areas were determined using equations form the Minnesota Pollution Control Agency, equations 1 and 2 below. The area of impervious surface area and depth of ponded water are used to determine the required bioinfiltration surface area.

Equation 1:

$$A_S = \frac{V_w}{D_0}$$

Equation 2:

$$V_w = 0.0833A_c$$

Where:

A_s = Surface area of bioinfiltration practice
V_w = Water treatment volume of the area contributing runoff to the practice
D_0 = Storage depth of ponded water in the practice
A_c = Impervious surface area contributing to the practice

Underdrain pipes were are sized based on the maximum flow rate, using the following equation (NCDENR, 2009):

Equation 3:

$$D = 16\left(\frac{Q * n}{S^{0.5}}\right)^{3/8}$$

Where:
D = diameter of single pipe (inches)
n = roughness factor (recommended to be 0.011)
s = internal slope (recommended to be 0.5%)
Q = flow rate (cfs)

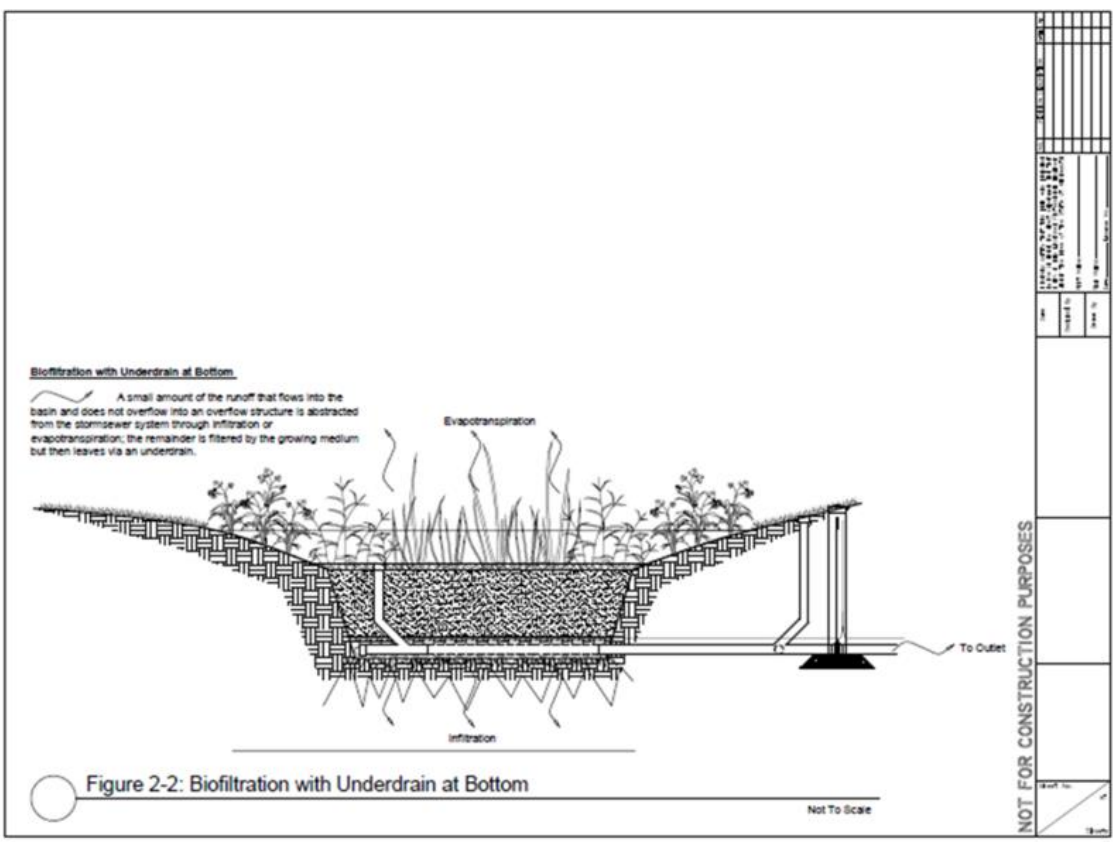

Figure 3: Bioretention cell with underdrain at the bottom (MPCA, 2017).

The effectiveness of different LID scenarios is compared using the Effectiveness Index (EI), developed for the L-THIA-LID model (Ahiablame et al., 2012).

Equation 4:

$$EI_{LID} = 100\left|\frac{Y_{NoLID} - Y_{LID}}{Y_{LID}}\right|$$

Where:

Y= Runoff or Infiltration value, with or without lid implementation

Study Area and Data

The city of Fayetteville, Arkansas has experienced rapid urbanization in the past years as it continues to grow. Within the city, the University of Arkansas lies on the border of two watersheds, the Cedar Creek–Illinois Watershed to the North, and the West Fork–White River Watershed to the South (fig. 4). The focus of this analysis is the West Fork – White River Watershed. The University of Arkansas Campus, extending to the neighborhoods on the West side, and extending down Dickson Street on the East side, drains to two outlet points, Mullins Creek on the east side, and Tanglewood Branch Creek on the West side.

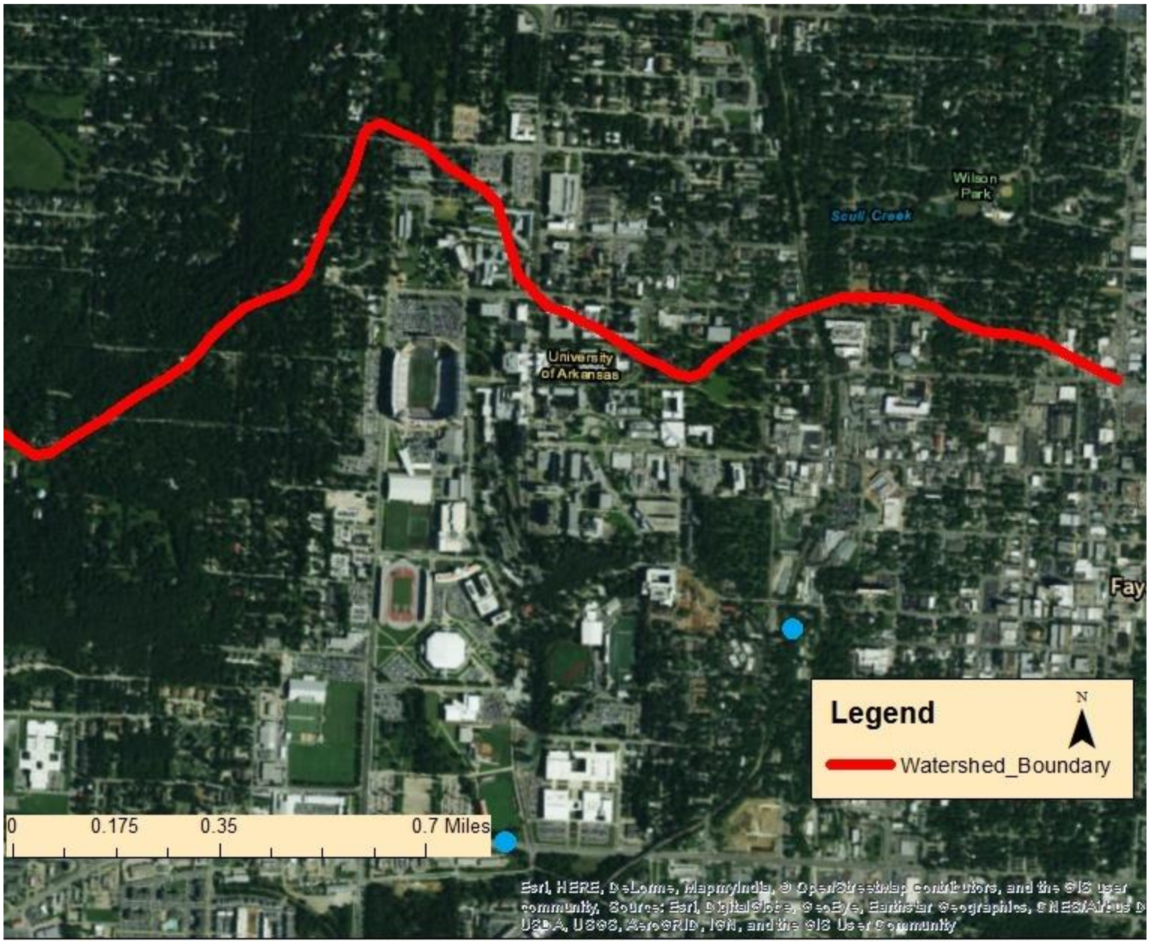

Figure 4: The University of Arkansas Campus within the West Fork – White River Watershed, draining to Mullins Creek and Tanglewood Branch Creek; outlets are marked in blue.

MULLINS CREEK

Mullins Creek (fig. 5) flows through the University of Arkansas from Leroy Pond Drive, just south of Bud Walton Arena, to its outlet between Lot 56 and the Women's soccer field, where the stream is routed under Martin Luther King Boulevard (MLK). As a tributary to Town Branch which flows into the West Fork - White River, Mullins Creek eventually leads to Beaver Lake, along with any sediment and pollutants it carries (WCRC). Beaver Lake is the primary drinking water source for Northwest Arkansas.

Figure 5: Mullins Creek flowing from Leroy Pond Drive (upper left) to Martin Luther King Boulevard (lower right).

Runoff from a large portion of campus is routed to Mullins Creek. The majority of the area north of Mullins Creek is impervious, with large built structures including Razorback Stadium and Bud Walton Arena. Additionally, the east side of Stadium Drive has steep slopes of up to 20%, causing increased velocities and flows leading to Mullins Creek. The east side of Razorback road is lined with impervious parking lots. Further East is a large residential area with increasing slopes of up to 20%, causing increased velocities and flows from the East. Increased velocities and flows can lead to streambank erosion, not only damaging local ecosystems, but increasing sediment and pollutant loads downstream. The entire drainage area is 740 acres (fig. 9).

A portion of the channel was recently restored by the Watershed Conservation Resource Center (WCRC), stabilizing and revegetating the streambanks, and implementing measures to reduce erosion and the associated sediment and nutrient loads (fig. 6-7). Many of the issues it faced associated with streambank erosion were alleviated. However, the southern end still has reported issues including streambank erosion and downstream flooding, due to both the unnatural course of the stream (90 degree angle) and the large volume of runoff received (fig. 8).


Figure 6-7: Mullins Creek before (left) and after (right) restoration efforts by the Watershed Conservation Resource Center (WCRC).

Figure 8: Existing streambank erosion at the southern end of Mullins Creek by Martin Luther King Blvd.

Parking Lot 56 was chosen as the optimal location for LID implementation. The area consists of 12.4 acres of impervious parking lot, providing optimal opportunity for capturing and treating runoff before it reaches Mullins Creek.

The area of Lot 56 is approximately 12 acres. According to the Minnesota Pollution Control Agency, a single bioretention cell should have a drainage area of 5 acres or less (MPCA, 2017). Lot 56 was split into four subcatchments of approximately 3.1 acres, shown in Figure 9 below. It was determined that a total area of 1.02 acres is required for 12 acres, with a storage depth of 1 foot. Each subcatchment, with an area of 3.1 acres, requires 0.26 acres of bioretention surface area.

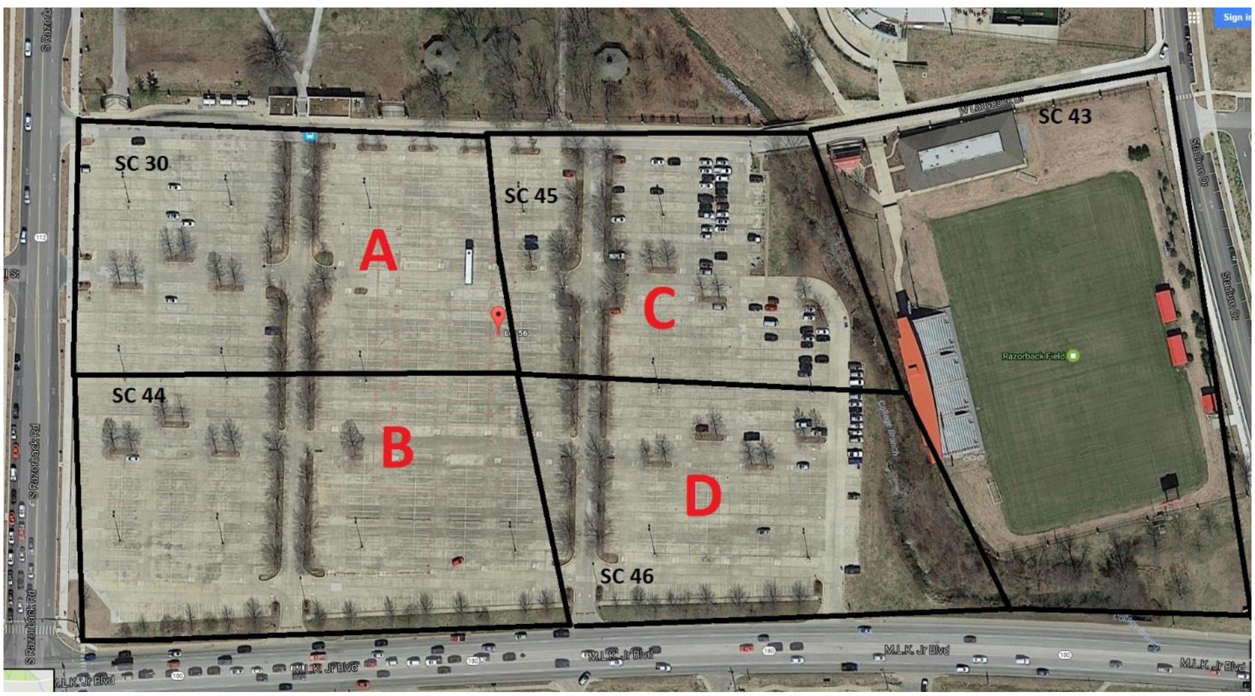

Figure 9: Lot 56 divided into four subcatchments: A, B, C, and D.

Two layouts were created for the implementation of Bioretention cells for Lot 56. Layout 1, the condensed layout, consists of five larger bioretention cells (Figure 12), and Layout 2, the dispersed layout consists of 29 cells distributed throughout the lot (Figure 13).

The Condensed Layout (1) consists of 5 cells placed in subcatchments A-D (figure 10). Subcatchment A contributes to cell 1, Subcatchment B contributes to cell 3, and cell 2 is split between A and B. Subcatchment C contributes to cell 4, and subcatchment D contributes to cell 5. The areas of the cells are 0.2 acres for cells 1, 2, and 3, and 0.36 acres for cell 4, and 0.39 acres for cell 5, with a total area of 0.95 acres. This layout requires the removal of approximately 116 parking spaces.

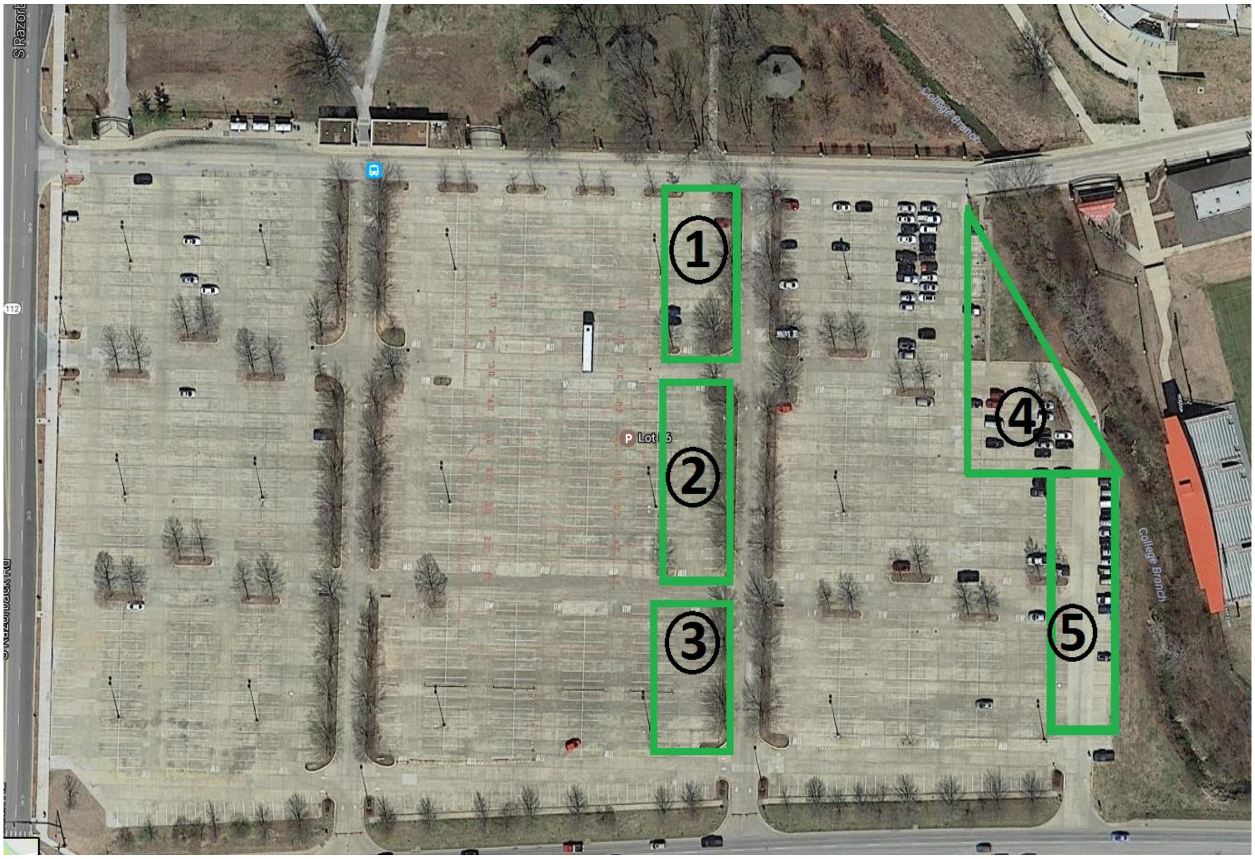

Figure 10: Condensed Bioretention Cell Layout (1) with five larger bioretention cells.

The Dispersed Layout (2) consists of 29 cells (fig. 11). Cells three and four are identical to the Condensed Layout. Twelve cells of type one, with areas of 0.028 acres, and 15 cells of type two, with areas of .007 acres, are distributed throughout the parking lot, at existing medians. Subcatchment A contributes to 3 type 1 cells and 7 type 2 cells. Subcatchment B contributes to 3 type 1 cells and 3 type 2 cells. Subcatchment C contributes to 3 type 1 cells, 2 type 2 cells, and cell 3. Subcatchment D contributes to 3 type 1 cells, 3 type 2 cells, and cell 4. Cell 4 has an area of 0.36 acres, and cell 5 has an area of 0.39 acres, for a total area of 1.18 acres. This layout requires the removal of approximately 89 parking spaces.

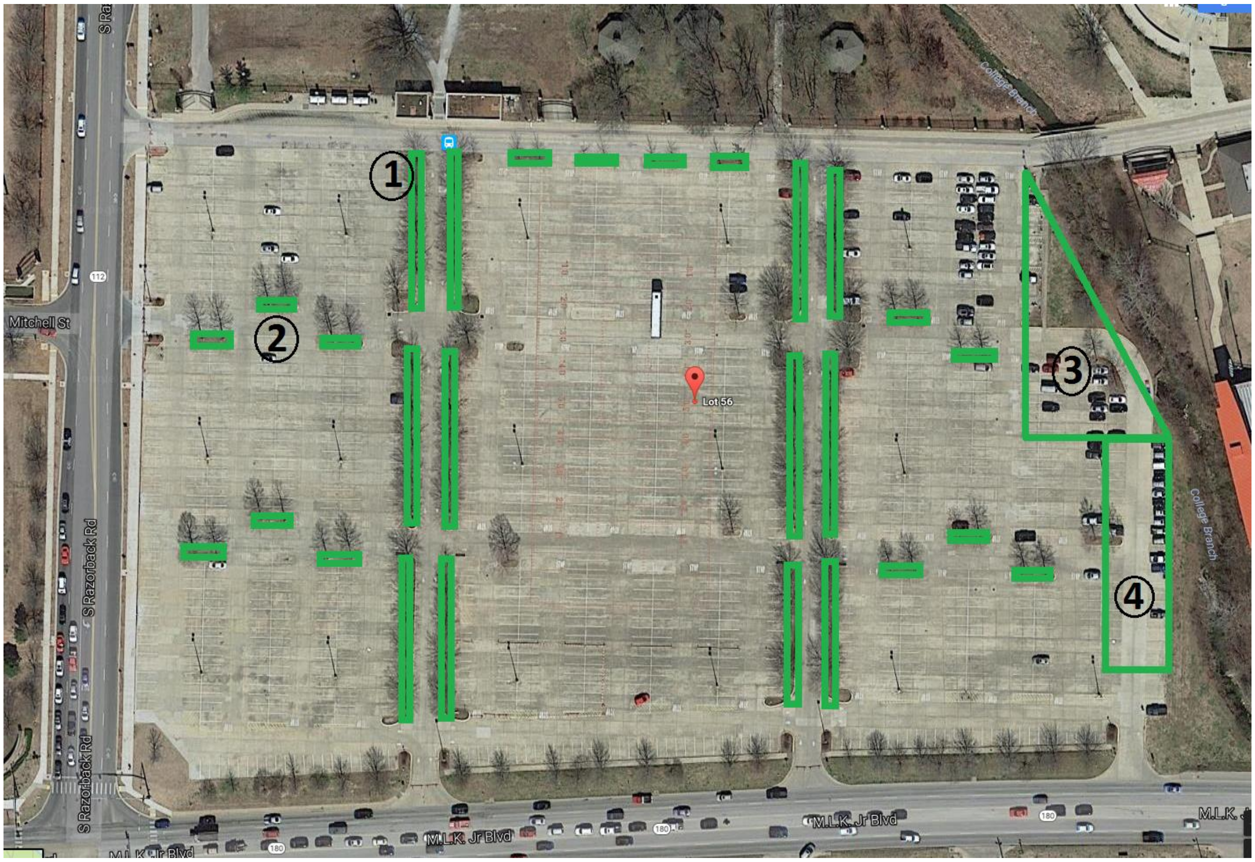

Figure 11: Dispersed Bioretention Cell Layout (2) with 29 smaller cells.

The two layouts were modeled in SWMM, along with a base model as the lot exists now. The bioretention cells were modeled with 24 inches of engineered soil, a berm height of 12 inches, and with an underlying 12 inch gravel storage layer. The engineered soil is modeled as an "enhanced filtration blend" from the MPCA bioretention design criteria, with 70-85% construction sand, and 15-30% organic matter (MPCA, 2017). Parameters were determined assuming sandy soils and dense vegetation growth. All cells have identical parameters, other than area, length, and the seepage rate to the outer soil. Subcatchments A-B consist mostly of sloan silt loam (Sn) beneath the parking lot. Subcatchments C-D are mostly leaf silt loam (Le) beneath the parking lot. A bioretention cell as modeled in SWMM is shown in Figure 12 below.

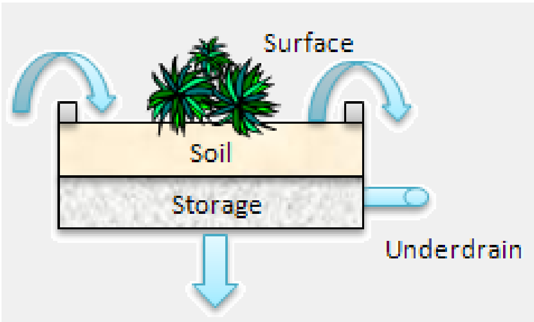

Figure 12: Bioretention cell as modeled in EPA SWMM (EPA, 2015).

Due to the limited infiltration provided by the native soils, underdrains are recommended. Underdrain sizes were calculated from peak runoff values for the 25 year storm using Equation 3. Calculated diameters are 2.4, 2.3, 2.4, and 2.3 inches for Lot 56 A, B, C, and D, respectively. Bioretention cells should have underdrains with a minimum diameter of 4 inches (MPCA, 2017). Therefore, each bioretention cell is designed with two 4 inch underdrains, with the second serving as backup in case of clogging.

Results

Stage 1 – Campus within the West Fork – White River watershed

The area of campus in the West Fork-White River watershed, routed to two outlet points, (Mullins Creek and Tanglewood Branch Creek), was modeled in SWMM to determine areas of interest on campus. Runoff and Infiltration values were analyzed the two drainage areas. Subcatchments with both high runoff and high peak runoff values were located, shown in figure 13 below.

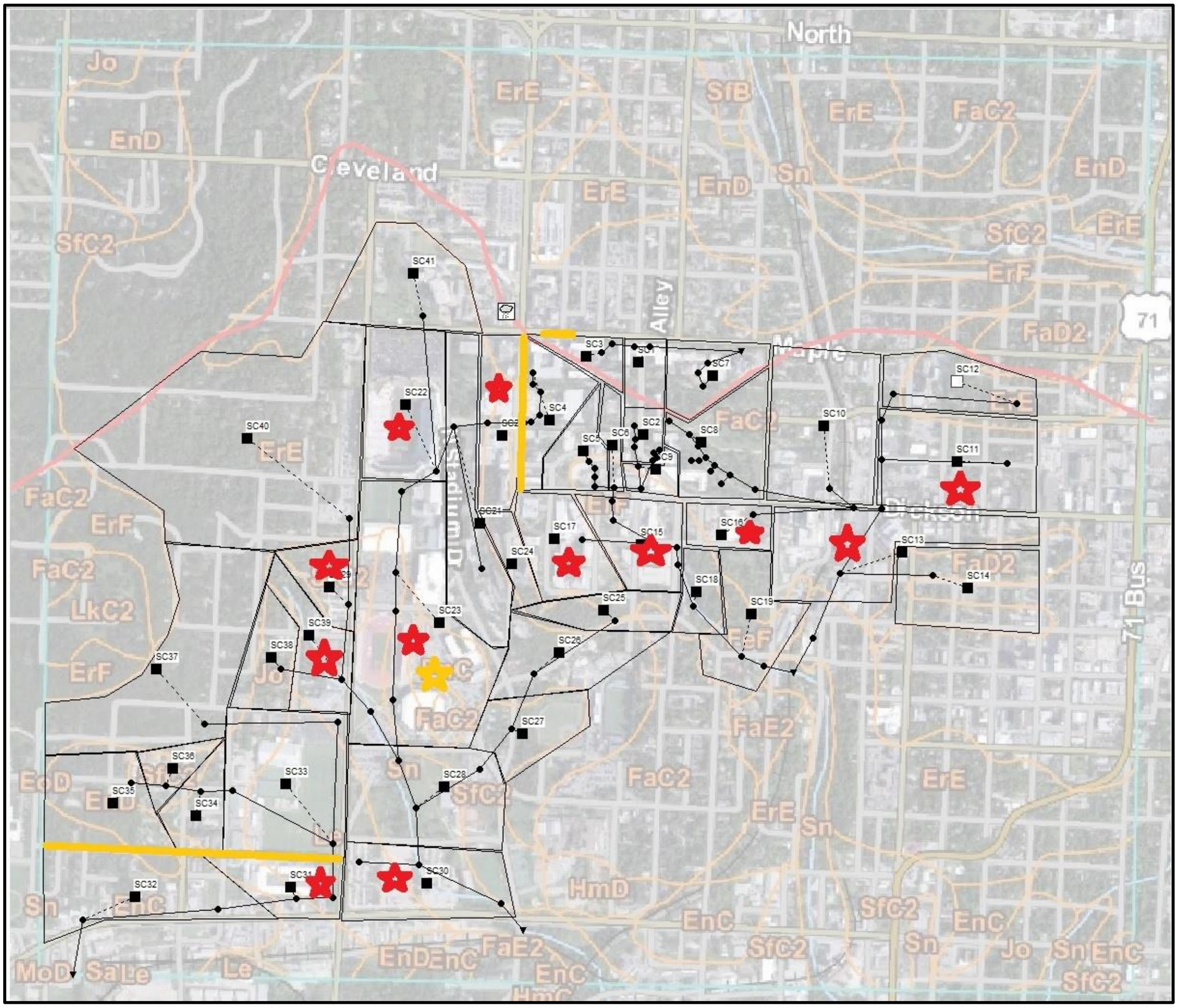

Figure 13: SWMM Model, with areas of high runoff denoted by red stars, and areas of high peak runoff denoted by yellow stars.

The results show that areas with high runoff are widely dispersed throughout campus. Subcatchment 23, which contains Bud Walton and other athletic facilities, has exceptionally high peak runoff. There is not a single area that is significantly worse. However, after consulting with the Facilities Management Director of Planning & Deign, Jay Huneycutt, it was determined that Mullins Creek has exceptional issues with streambank flooding and erosion. Therefore, stage two of the analysis focused on the Mullins Creek drainage area. The subcatchments draining to Mullins Creek are shown in figure 14.

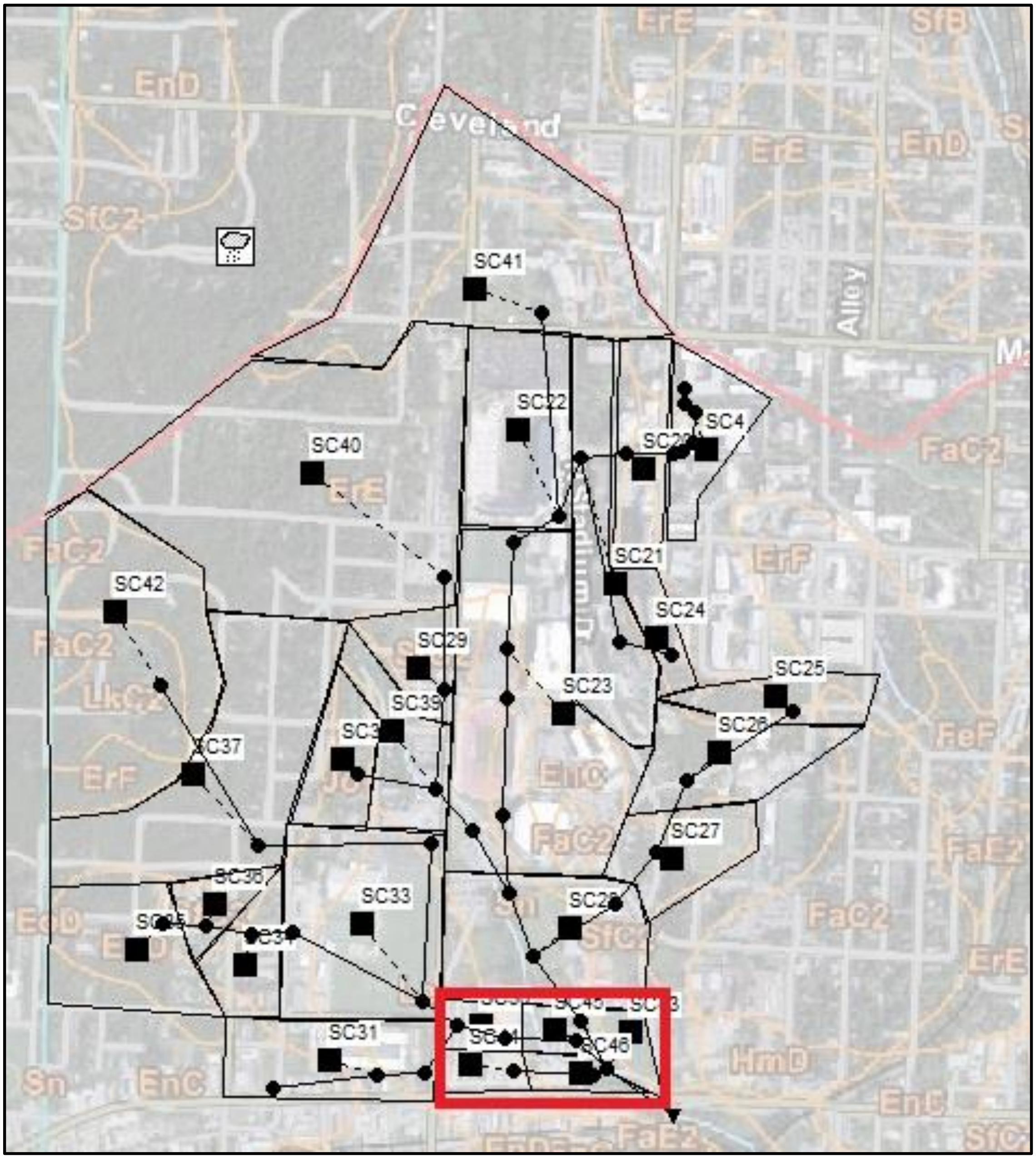

Figure 14: SWMM model of the area draining to Mullins Creek at Martin Luther King Boulevard, with Lot 56 outlined in red.

Stage 2 - Single Drainage Area

Stage two of the analysis focused on the portion of campus draining to Mullins Creek. A new model was developed for the subcatchments within this drainage area (fig. 14), which extends beyond campus to neighborhoods to the east.

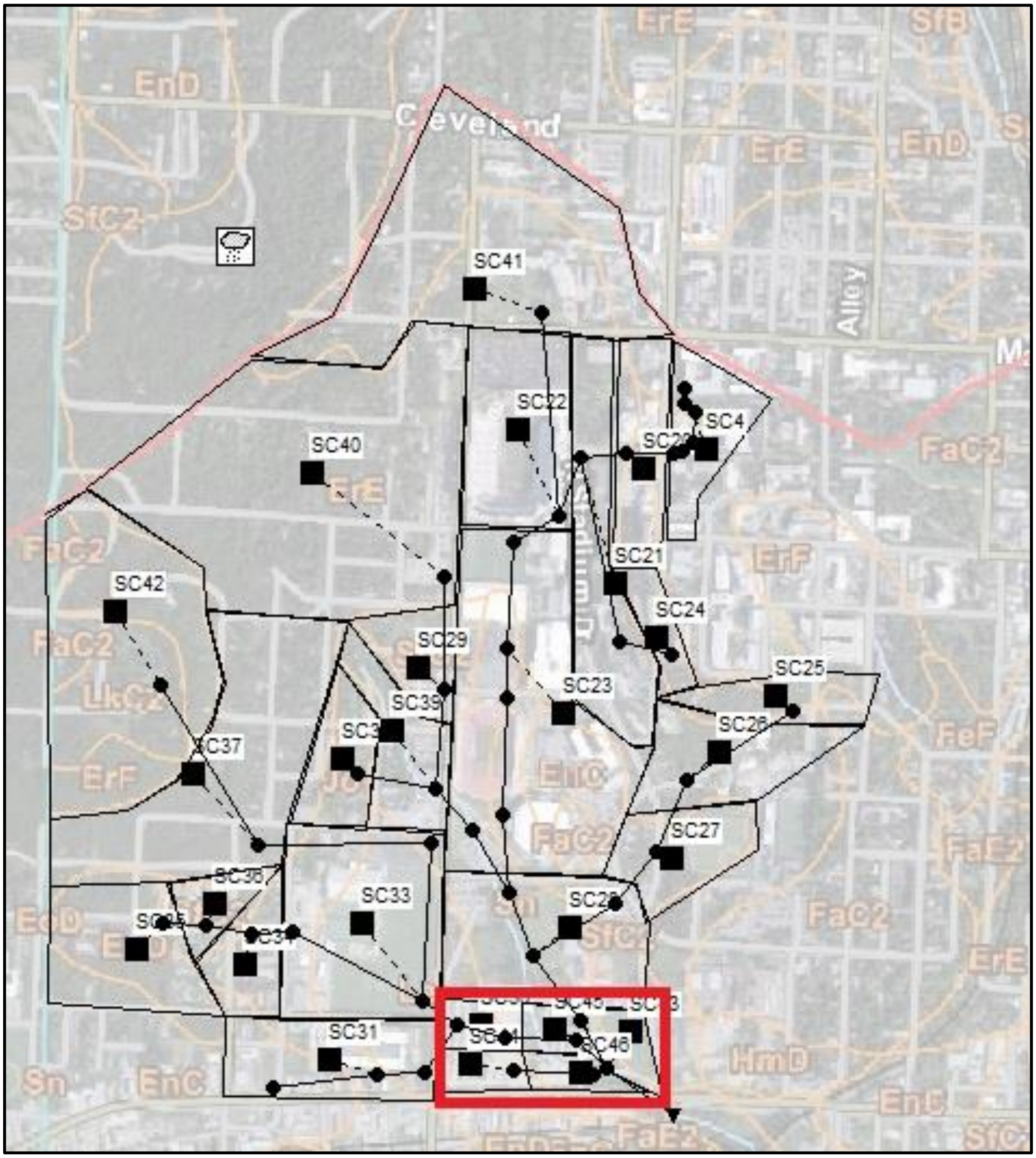

Figure 14: SWMM model of the area draining to Mullins Creek at Martin Luther King Boulevard, with Lot 56 outlined in red.

Runoff and infiltration values for the drainage area were calculated for each subcatchment. The rainfall not accounted for in infiltration and runoff values goes to depression storage. The results were analyzed to determine the greatest cause of runoff to Mullins Creek. The runoff coefficient is the ratio of total runoff to total precipitation, so a higher runoff coefficient correlates to a higher proportion of runoff. Runoff and infiltration values are shown in tables 2-3 in both inches and gallons.

Table 2: SWMM results for subcatchments east of Razorback Road for the two-year storm (3.92 in.).

East of Razorback Rd.							
Subcatchment	Area (acres)	CN	Slope (%)	Infiltration (in.)	Runoff (in.)	Runoff (10^6 gal)	Runoff coeff
SC4	11	86	6	0.47	3.19	0.95	0.807
SC20	10.7	96	18	0.04	3.78	1.1	0.957
SC21	13.3	84	18	0.84	2.26	0.82	0.573
SC22	22.4	97	6	0.03	3.84	2.34	0.972
SC23	50	97	4	0.03	3.85	5.23	0.975
SC24	4	87	20	0.55	2.73	0.3	0.692
SC25	9.1	82	15	1.07	2.00	0.49	0.507
SC26	10.7	89	12	0.38	3.12	0.91	0.789
SC27	14.1	92	5	0.36	3.25	1.24	0.822
SC28	23.5	84	4	0.65	2.97	1.89	0.751
SC30	3.3	97	0.5	0.01	3.91	0.35	0.989
SC43	5.2	83	3	1.02	2.53	0.36	0.64
SC44	3.3	97	0.5	0.22	3.31	0.3	0.839
SC45	3.3	96	0.5	0.04	3.44	0.31	0.87
SC46	3.3	95	0.5	0.07	3.54	0.32	0.896
Total/Avg.	**187.2**	**91.7**	**7.5**	**0.33**	**3.32**	**16.91**	**0.84**

Table 3: SWMM results for subcatchments west of Razorback Road for the two-year storm (3.92 in.).

West of Razorback Rd.							
Subcatchment	Area (acres)	CN	Slope (%)	Infiltration (in.)	Runoff (in.)	Runoff (10^6 gal)	Runoff coeff
SC29	7.8	96	5	0.04	3.84	0.81	0.973
SC31	10.7	97	3	0.01	3.91	1.14	0.989
SC33	28.8	92	3	0.29	3.44	2.69	0.871
SC34	4.6	92	6	0.29	3.37	0.42	0.853
SC35	18.4	92	8	0.29	3.32	1.66	0.84
SC36	4.6	92	7	0.21	3.5	0.44	0.885
SC37	38.5	80	15	1.32	1.55	1.62	0.393
SC38	9.7	93	7	0.22	3.44	0.91	0.872
SC39	11	96	5	0.04	3.84	1.15	0.972
SC40	78.7	85	12	0.74	2.54	5.43	0.643
SC42	48.5	81	3	1.13	1.95	2.57	0.494
Total/Avg.	**261.3**	**87**	**8.25**	**0.7**	**2.65**	**18.84**	**0.7**

The results showed that the area east of Razorback Road produces more total runoff than the west, despite the smaller area. The average infiltration (in.) for the west side is two times the average for the east. The average runoff (in.) is approximately 25% greater for the east side than the west. The average runoff coefficient is approximately 20% greater for the east side, which reveals that a larger percentage of rainfall is converted to runoff. Since the east side produces more runoff, both in volume and per area, LID implementation was focused on the east side, specifically at Lot 56.

Stage 3 - Small-Scale LID

A new model was developed in SWMM, with the subcatchment containing Lot 56 divided into four smaller subcatchments. Total runoff and infiltration values were calculated for Lot 56 subcatchments A-D (see fig. 9) for both the Condensed Layout (1) and the Dispersed Layout (2). Results are shown in tables 4-5.

Table 4. Condensed Layout (1) Results

Subcatchment	Area	Infiltration (10^6 gal)	Runoff (10^6 gal)	Peak Runoff (CFS)
SC30	3.3	0.02	0.13	0.71
SC44	3.3	0.04	0.08	0.68
SC45	3.3	0.28	0.01	0.03
SC46	3.3	0.28	0.01	0.03
Lot 56	**13.2**	**0.62**	**0.23**	**0.70**

Table 5. Dispersed Layout (2) Results

Subcatchment	Area	Infiltration (10^6 gal)	Runoff (10^6 gal)	Peak Runoff (CFS)
SC30	3.3	0.01	0.27	0.72
SC44	3.3	0.03	0.23	0.70
SC45	3.3	0.28	0.02	0.06
SC46	3.3	0.29	0.01	0.03
Lot 56	**13.2**	**0.61**	**0.53**	**1.51**

The results showed significant increase in infiltration and decrease in runoff for both layouts compared to existing conditions. The Condensed Layout (1) had greater infiltration significantly lower runoff than the Dispersed Layout (2).

Table 6. Comparison of results between no LID, layout 1, and layout 2

	Lot 56		
Scenario	Infiltration (10^6 gal)	Runoff (10^6 gal)	Peak Runoff (CFS)
No LID	0.03	1.28	2.91
Layout 1	0.62	0.23	0.70
Layout 2	0.61	0.53	1.51

Both layouts increased infiltration approximately 20 times the value for no LID. The total runoff was decreased by 82% for layout 1, and by 59% for layout 2. The effectiveness index (EI), developed for the L-THIA-LID model, was used to directly compare both layouts (equation 4, page 8). Results are shown in table 7.

Table 7. Effectiveness Index for layouts 1 & 2

Lot 56			
Scenario	EI (Infiltration)	EI (Runoff)	EI (Peak Runoff)
Condensed Layout (1)	92	2460	316
Dispersed Layout (2)	94	142	93

Both layouts have similar effectiveness at increasing infiltration, but the Condensed Layout (1) is significantly more effective at reducing both total and peak runoff.

Lot 56 Effects on Entire Drainage Area

The entire drainage area was analyzed in order to determine the effects of LID implementation at Lot 56 to the total runoff into Mullins Creek. Infiltration and runoff were further analyzed based upon hourly data over the course of the 24 hour storm. Infiltration maintained the same curve for both layouts, with a slight increase for the drainage area compared to existing conditions. The infiltration curve is shown in figure 15 below.

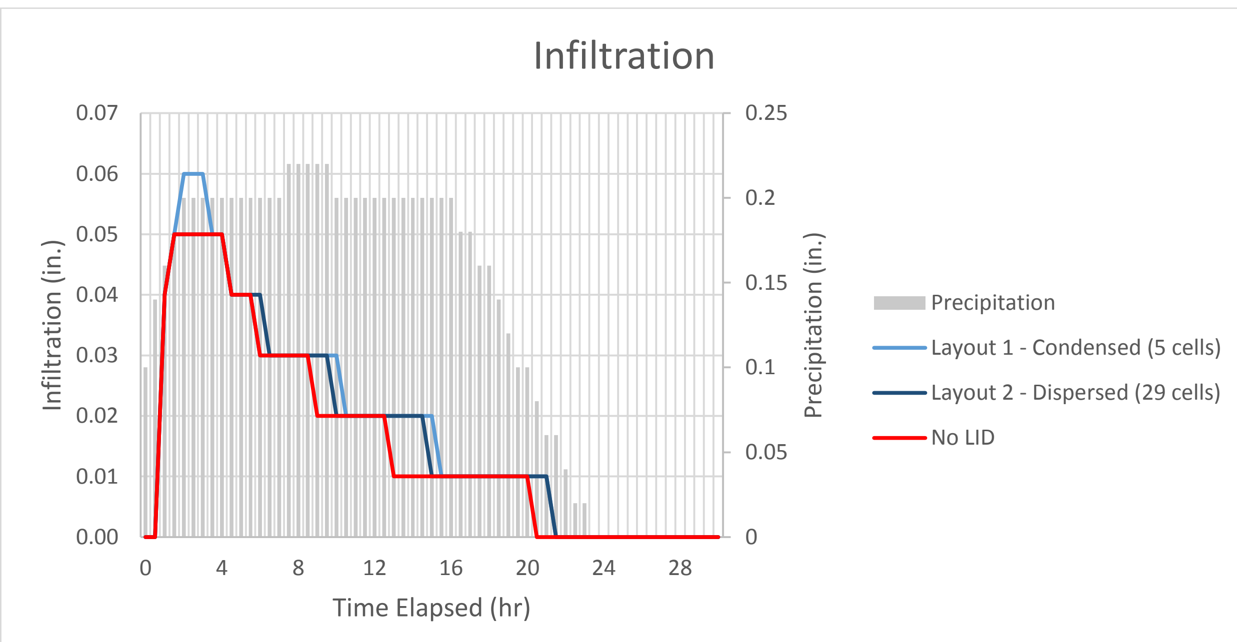

Figure 15: Infiltration for a 2 year, 24 hour storm for the entire drainage area; with two LID and the existing scenarios; the design storm precipitation is shown with its scale on the right-hand axis.

The runoff curves for the two layouts are nearly identical to the existing conditions. The two LID layouts produce a very small decrease during the middle of the storm. The runoff curves are shown in figure 16 below.

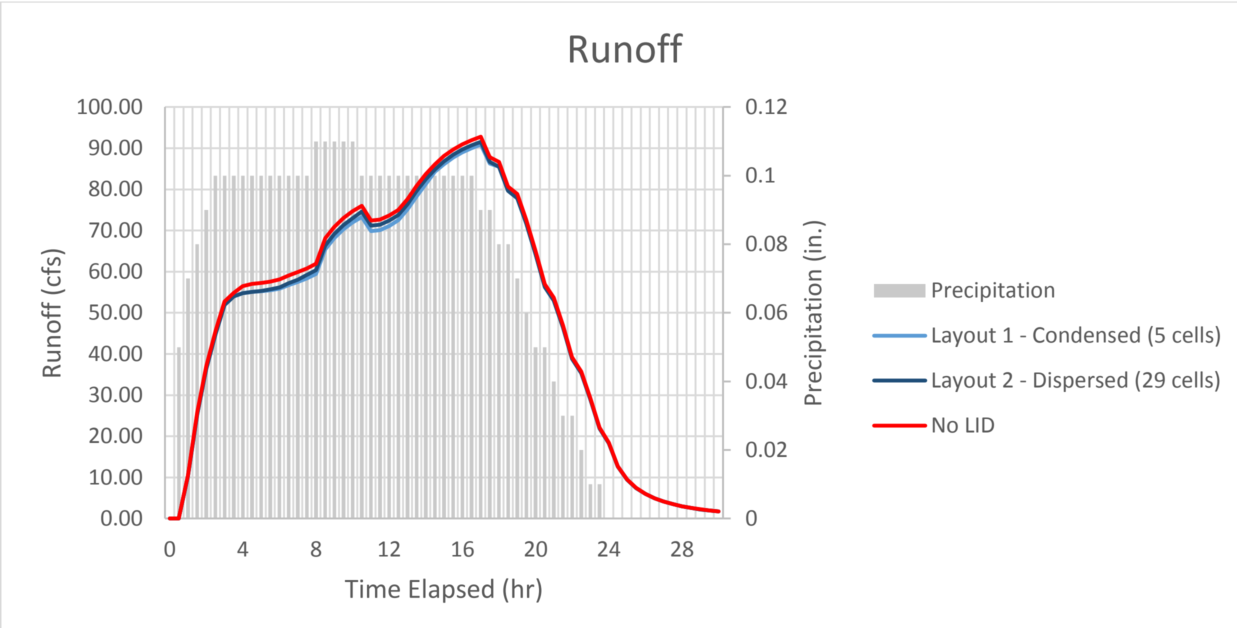

Figure 16: Runoff for a 2 year, 24 hour storm for the two LID and the existing scenarios; the design storm precipitation is shown with its scale on the right hand axis.

The change in overall runoff is extremely small for both layouts. Total runoff was decreased by 2.6% for layout 1, and by 1.8% for layout 2. Results are shown in table 8.

Table 8. Total runoff from entire drainage area for each scenario

Entire Drainage Area	
Scenario	Runoff (10^6 gal)
No LID	40.74
Layout 1	36.69
Layout 2	39.99

Cost Analysis

Typical costs for bioretention cells in slowly permeable soils range from \$4.00 to \$6.00 per square foot (Penn State Extension, 2017). Estimated costs are \$165,880 - \$248,820 for Layout 1, and \$206,172 - \$309,258 for Layout 2.

Additionally, bioretention cells may require some seasonal maintenance, such as weed control and litter removal. This generally costs about \$550 per 900 ft2 of bioretention area annually (Upstate Forever, 2017). These maintenance costs are significantly lower than a wet detention pond (Upstate Forever, 2017). This gives a total maintenance cost of approximately \$25,289/year for Condensed Layout (1), and \$31,412/year for Dispersed Layout (2). Soils need to be tested for pH annually, and inflow point need to be inspected for clogging (Upstate Forever). Additionally, smaller bioretention cells may be more prone to weed invasion, and therefore may have an increased maintenance cost (Water by Design, 2015).

Discussion and Future Opportunities

From the SWMM model results, it is concluded that the implementation of bioretention cells at Lot 56 can significantly reduce runoff from the parking lot into Mullins Creek. With the ideology of volume–based hydrology (VBH), we can assume that the runoff reduction will thereby reduce the erosion and flooding seen in Mullins creek, as well as reducing pollutant and sediment loads. However, LID implementation at Lot 56 had a relatively small effect on the total runoff load into Mullins Creek.

Implementing LID solutions to one subarea may have a large effect on the subarea, but has little effect at the watershed scale. More interventions throughout a drainage area are necessary. By implementing more LID structures throughout the Mullins Creek drainage area, as well as small-scale changes to change the curve number, the total runoff into the creek could be significantly reduced, with the potential to alleviate the flooding and erosion issues downstream.

Condensed vs. Dispersed Layouts

Layout 2 has the benefit of disconnecting impervious area with many smaller cells, and would be expected to perform better than Layout 1, with smaller, concentrated cells. However, it was less effective overall based upon the model in SWMM. Layout 1 was significantly more effective, despite having a lower area of bioretention cells. This is most likely due to the functioning of the model, and it is not expected that the actual system would give these results.

While SWMM successfully computes the behavior of individual subcatchments, it is not always accurate in the analysis of water flow between subcatchments. SWMM works by calculating the runoff for each subcatchment. This runoff is then routed directly to the outlet. So in a situation where water would actually flow from one subcatchment to the next (such as across lot 56) the model fails to account for this behavior.

As a brief experiment, I modeled Layout 2 as a single subcatchment instead of 4 smaller subcatchments, in order to explore the influence of SWMM's architecture. The new subcatchment contained the same bioretention cells as the original layout. When evaluated with the new model, the infiltration for Layout 2 increased from 530,000 gallons to 920,000 gallons. Runoff decreased from 530,000 gallons to 19,000 gallons. The Dispersed Layout (2), which has 24% greater bioretention area than the Condensed Layout (1), performed better with 50% greater infiltration, 18% less runoff, and a 50% reduction in peak runoff. Therefore, the difference between the results for the two layouts is influenced greatly by the model construction. Further analysis using a different modeling approach is necessary to compare scenarios with more, disconnected cells to that of less, concentrated cells.

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References

Ahiablame, L. M., Engel, B. A., & Chaubey, I. (2012). Effectiveness of low impact development practices: literature review and suggestions for future research. *Water, Air, & Soil Pollution*, *223*(7), 4253-4273.

Ahiablame, L. M., Engel, B. A., & Chaubey, I. (2012). Representation and evaluation of low impact development practices with L-THIA-LID: An example for site planning. *Environment and Pollution*, *1*(2), 1.

Campus, H., & Markham, O. N. (2015). Hydrologic Assessment of LID. Retrieved from: http://www.sustainabletechnologies.ca/wp/wp-content/uploads/2015/03/Honda_TechBrief_March2015r.pdf

City of Fayetteville. (2014). Drainage Criteria Manual. Retrieved from http://www.fayetteville-ar.gov/DocumentCenter/Home/View/2248

Davis, A. P. (2008). Field performance of bioretention: Hydrology impacts. *Journal of Hydrologic Engineering*, *13*(2), 90-95.

Department of Environmental Resources. (2007). Bioretention Manual. The Prince George's County, Maryland. Retrieved from: http://www.ct.gov/deep/lib/deep/p2/raingardens/bioretention_manual_2009_version.pdf

EPA. (2015). Storm Water Management Model User's Manual. Version 5.1. Retrieved from: https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100N3J6.TXT

EPA. (2016). Storm Water Management Model Reference Manual. Vol 1 – Hydrology. Retrieved from: https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100NYRA.txt

Geographic Information Systems. GIS Interactive Maps. Fayetteville, AR. Retrieved from: http://gis.fayetteville-ar.gov/GISPage/GeneralReference/

Gholamreza-Kashi, S., Tiveron, T., & Joksimovic, D. (2016). ENV-648: Design Optimization for Enhanced Pollutant Removal Efficiency of Bioretention Cells. Retrieved from: http://ir.lib.uwo.ca/cgi/viewcontent.cgi?article=1272&context=csce2016

LeFevre, G. H., Paus, K. H., Natarajan, P., Gulliver, J. S., Novak, P. J., & Hozalski, R. M. (2014). Review of dissolved pollutants in urban storm water and their removal and fate in bioretention cells. *Journal of Environmental Engineering*, *141*(1), 04014050.

Liu, Y., Ahiablame, L. M., Bralts, V. F., & Engel, B. A. (2015). Enhancing a rainfall-runoff model to assess the impacts of BMPs and LID practices on storm runoff. *Journal of Environmental Management*, *147*, 12-23.

Minnesota Pollution Control Agency. (2017). Design Criteria for Bioretention. Retrieved from: https://stormwater.pca.state.mn.us/index.php/Design_criteria_for_bioretention

NOAA National Weather Service. (2014). NOAA Atlas 14 Point Precipitation Frequency Estimates: AR. Retrieved from: http://hdsc.nws.noaa.gov/hdsc/pfds/pfds_map_cont.html?bkmrk=ar

North Carolina Department of Environment and Natural Resources. (2009). Stormwater BMP Manual. Retrieved from: https://ncdenr.s3.amazonaws.com/s3fs-public/Water%20Quality/Surface%20Water%20Protection/SPU/SPU%20-%20BMP%20Manual%20Documents/BMPMan-Ch05-BMPDesignElem-20090716-DWQ-SPU.pdf

NRCS. (2016). Web Soil Survey. Retrieved from: https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm

Pennsylvania State Extension. (2017). Rain Gardens (Bioretention Cells) – a Stromwater BMP. Retrieved from: file:///C:/Users/mecrowl/Downloads/F-263.pdf

Peterein, M., Kandissounon, G. A. A. D., Kalra, A., & Ahmad, S. (2016). Improvements to SIU's Engineering Campus Parking and Walkways along Campus Lake. *World Environmental and Water Resources Congress* (pp. 262-271).

Rushton, B. T. (2001). Low-impact parking lot design reduces runoff and pollutant loads. *Journal of Water Resources Planning and Management*, *127*(3), 172-179. Retrieved from: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.514.6509&rep=rep1&type=pdf

Upstate Forever. (2017). LID Fact Sheet: Bioretention. Retrieved from: https://upstateforever.org/pdfs/other/CAW_LIDFact_Bioretention.pdf

Water by Design. (2015). Guide to the Cost of Maintaining Bioretention Systems. Healthy Waterways Initiative. Retrieved from: http://hlw.org.au/u/lib/mob/20150213075847_0731a67b612832545/wbd_2015_guide-cost-maintain-bioretention_mq_online.pdf

WCRC. Mullins Branch Stream Restoration Project. Retrieved from: http://www.watershedconservation.org/proj_mullins.html

Vogel, J. R., Moore, T. L., Coffman, R. R., Rodie, S. N., Hutchinson, S. L., McDonough, K. R., McLemore, A. J., McMaine, J. T. (2015). Critical review of technical questions facing low impact development and green infrastructure: A perspective from the Great Plains. *Water Environment Research*, *87*(9), 849-862. Retrieved from: http://www.ingentaconnect.com/contentone/wef/wer/2015/00000087/00000009/art00010?crawler=true