Assessment of and Solutions to the Stormwater Management System of Auburn University Campus in Auburn, Alabama

Alamin Molla, Chandana Mitra, and Jose Vasconcelos

Auburn University, Auburn, Alabama.

Abstract

Stormwater management needs attention as it causes surface flooding and pollution of nearby waterbodies. Parkerson Mill Creek in Auburn University, which gets polluted through surface runoff, is an example of this. In this study, a Personal Computer Stormwater Management Model (PCSWMM) was used to determine the susceptibility of the existing stormwater network to flooding on the Auburn University campus. Maximum water velocity mapping was used to identify areas associated with 3 categories of velocity (high, medium, and low) to find areas of potential erosion. Among the various sustainable stormwater management initiatives, it was found through a literature review that bioretention cells had the greatest potential to improve stormwater quality by screening pollutants from runoff water as well as minimizing erosion by reducing surface water velocity. Suitability analysis for bioretention cells identified 8 areas on the campus where bioretention cell could be installed for the most effective stormwater management. This study highlights the usability of PCSWMM models and techniques in increasing the efficiency of the stormwater system in any locality.

1 Introduction

Rapid uncontrolled and unplanned urbanization causes severe problems in the immediate urban area and in surrounding areas (Larsen et al. 2016; Yang et al. 2014). The most noticeable outcome of urbanization is the increased proportion of impervious surfaces. Rapid urbanization transforms once vegetated porous land to hard impervious surfaces. Increased imperviousness causes frequent urban flooding and waterlogging issues, which are common experiences for most city dwellers globally (Yao et al. 2017; Zhou et al. 2017; Zhang et al. 2018; Li et al. 2017).

Increased imperviousness increases runoff during storm events. Stormwater runoff has adverse impacts on nearby waterbodies. It causes pollution of streams, lakes and other waterbodies. In usual circumstances, stormwater infiltrates into the ground, percolates through layers, and finally replenishes groundwater storage. However, when the surface is impervious, then instead of infiltrating, water runs off and flows on the land surface to low lying areas. Runoff washes away pollutants and heavy metals from upstream developed areas to nearby downstream waterbodies, causing the water to become contaminated. Contaminated water cannot be used for drinking or household activities where safe and pure water is an essential requirement. Contaminated water also jeopardizes the lives of living organisms within the water environment.

Managing stormwater will significantly help to maintain the water quality of nearby waterbodies and reduce waterlogging and flooding of downstream areas. Stormwater management can be simply defined as controlling and using stormwater runoff in other activities where water quality is not of much concern (Holm et al. 2014). An effective, detailed stormwater management approach involves several steps, such as initially planning for runoff, then maintaining stormwater systems, and finally regulating the collection, storage and movement of stormwater (Holm et al. 2014).

1.1 Objectives of the study

This study focused on the following three interconnected objectives, where the first objective has been broken down into two subobjectives:

1. (a) Assess the susceptibility of the existing stormwater network at the Auburn University campus to flooding during extreme rainfalls.
   (b) Create a maximum water velocity map of the study area to detect areas with higher water velocity.

2. Use a PCSWMM model to assess the effects of LID placement on Auburn University campus drainage.

3. Conduct a suitability analysis test to find the best position for installing a bioretention cell within the Auburn University campus.

1.2 Study area

The goal of this study is to evaluate and assess the stormwater management plan for a university campus, making it convenient to manage data and models and get effective results. Auburn University was chosen as the study area for easy access to data and physical proximity to sites.
Auburn University is a public research university located in Auburn, eastern Alabama. It is a land, sea, and space grant university and was chartered in 1856. Currently there are 30,440 students pursuing different degree programs, at both the undergraduate and graduate level (Auburn at a Glance 2019).

The Google Earth image (Figure 1) shows that buildings and other concrete surfaces are the dominant land use on Auburn University campus. In addition to the Google Earth image, a quantitative estimate using the normalized difference vegetation index (NDVI) was performed to provide evidence that most of the landcover on the Auburn University campus is concrete (Figure 2). NDVI is a popular index for vegetation mapping or mapping of pervious surfaces and it gives detailed information about impervious surfaces (Kaspersen et al. 2015). NDVI was calculated using the National Agricultural Imagery Program (NAIP) image of Auburn from 2015-09-18.

The NDVI value range is −1 to +1, where a higher value indicates more vegetation. A negative value indicates no vegetation. Values close to zero (either positive or negative), here areas colored yellow, refer to impervious areas. Larger negative values refer to a waterbody. We can see that the Auburn University campus has most areas covered with impervious surfaces, particularly the north-eastern portion, and thus having higher surface runoff during a storm event. Auburn University has prepared its own Stormwater Management Program Plan (SWMPP) following guidelines provided in Title 40 Code of Federal Regulations (CFR), Part 122.26(d). This is a requirement by the U.S. Environmental Protection Agency Clean Water Act Phase II Stormwater Regulations since Auburn University is an owner–operator of a phase II municipal separate storm sewer system (ms4). Although the Auburn University SWMPP is a very detailed plan for stormwater management, it does not specify location specific measures to manage stormwater after a rain event. Keeping this in mind, this study will calculate low impact development (LID) effectiveness, as well as identifying potential locations for bioretention cell installation.

2 Literature review

2.1 Sustainable stormwater management

Most research on stormwater management has focused on increasing the capacity of stormwater drainage networks, which has proved to be ineffective in the long run (Bohman et al. 2020; Denchak 2019). Researchers are now moving towards sustainable ways to manage stormwater, such as permeable pavement (Figure 3), rainwater harvesting, rain gardens and bioretention cells (Figure 4) (Marlow et al. 2013).

These sustainable forms of stormwater management have additional ecological and economic benefits (Berland and Hopton 2014). If surface runoff is reduced and filtration of pollutants increases, then there is less chance of nearby waterbodies being polluted. This will also reduce cleanup costs. Natural beauty and air quality will improve due to planted trees in bioretention cells and flowers and shrubs in rain gardens. The groundwater table will also be recharged through infiltration. Researchers have found that bioretention cells are the most effective of the various stormwater management initiatives in screening pollutants from runoff, reducing the amount of stormwater runoff, and slowing peak flow speed (Davis et al. 2009; Lu and Yuan 2011; Johnson 2012; Liu et al. 2014).

Figure 1  Auburn University campus (Google Earth).

Figure 2  NDVI map of Auburn University.

Figure 3  Common permeable pavement systems (Imran et al. 2013).
2.2 Bioretention cells

Treatment of stormwater runoff is very important since it can pollute nearby waterbodies by carrying dissolved pesticides, nutrients, herbicides and heavy metals from developed areas and depositing them in nearby waterbodies (Hall 2015). One of the best methods of treating runoff is by installing a bioretention cell. A bioretention cell is a small, vegetated depression in the ground that can treat stormwater runoff coming from upslope developed areas. Various layers (e.g. grass filter strip, soil, sand) (Figure 5) are placed on top of one another in an engineered design for bioretention cell construction. Among the several benefits of bioretention cells, the capacity for removing up to 75% nitrogen from contaminated water, a relatively cheap installation cost, minimal maintenance cost, and ease of installation in small areas are worth mentioning (Hall 2015).

Designing an efficient stormwater management system is a crucial activity for civil and environmental engineers and city planners, as mismanagement could result in flood, erosion and water quality problems. There should be a sound approach to manage stormwater by considering local characteristics and various spatial, temporal, legal, economic and technical factors (Barbosa et al. 2012). These days, people rely on computer simulations and advanced mathematical modeling techniques to help plan and simulate water system performance for any location (Adams 2000). One such tool is the US EPA Stormwater Management Model (SWMM).

SWMM has been widely used all over the world for planning, analysis and design related to stormwater runoff, evaluating gray infrastructure stormwater control strategies, and creating green or gray hybrid stormwater control solutions (US EPA 2014). SWMM is one of the most preferred models to deal with watershed hydrology and water quality within an urban area (Xu et al. 2019; Krebs et al. 2013; Obropta and Kardos 2007). SWMM is a dynamic hydrologic–hydraulic water quality simulation model. It is primarily used for runoff quality and quantity simulation for single event or long term simulation for urban areas (“Storm Water Management Model | U.S. Climate Resilience Toolkit” 2019). SWMM was first developed as SWMM I back in 1971 by the United States Environmental Protection Agency (US EPA) for rainfall–runoff quality and quantity simulations. In 2005, SWMM 5 was released, written completely in C, with high computational capabilities and the capacity to add unlimited elements into the model (Niazi et al. 2017). Over the years, academics, researchers, policy makers, urban planners and urban thinkers have used SWMM 5 models in diverse applications, contributing to various stormwater management initiatives. The uniqueness of SWMM 5 lies in its ability to emphasize engineered water conveyance systems for stormwater runoff and wastewater management, which sets it apart from other urban watershed models (Niazi et al. 2017).

Types of data components in SWMM include:
- hydrology: rain gauges, subcatchments, snowpacks; and
- hydraulics: nodes (junction, outfall, divider) and links (conduit, orifice, weir, outlet).

Another important aspect of SWMM modeling is the continuity error, which determines the validity of analysis results. There are two kinds of errors: runoff continuity errors and routing continuity errors. These errors represent the percentage difference between initial storage + total inflow and final storage + total outflow for the entire drainage system (Rossman 2015). If these errors exceed a reasonable level, such as 10% (Rossman 2015), then the validity of the analysis results must remain questionable.

Since hydrological flow is a spatial phenomenon, it requires supporting data from other spatial data handling software such as ArcGIS. To overcome this problem, Computational Hydraulics Int. developed PCSWMM, which is a personal computer-based
combination of the SWMM engine and a geographic information systems (GIS) engine. This unique characteristic of PCSWMM makes it one of the most effective and efficient modeling tools for stormwater modeling (Kabbani 2015; Paule-Mercado et al. 2017).

Spatial characteristics play a vital role in hydrology, so GIS can contribute to stormwater modeling due to an inherent capacity for spatial data processing (Zhu 2010). The very first step in stormwater modeling of an area is catchment delineation. Previously, most of the delineation was done manually by hand-drawing on watershed maps (Dongquan et al. 2009), but for the past few decades it has been done using different online techniques, tools or software (Tikkanen 2013). Although it is always best to have the customized model for an area validated through calibration, noncalibrated models can also provide significant results in some analyses, such as measuring the effects of climate change on urban water balance (Tikkanen 2013). Before PCSWMM was available, spatial analysis within SWMM was done by coupling it with ArcGIS (Wang et al. 2018). This coupling approach could significantly improve urban flood modeling, resulting in less damage during floods (Wang et al. 2018), and apply it to larger watersheds (Barco et al. 2008). Coupling of one-dimensional (1D) SWMM models with two-dimensional (2D) models could help to reasonably predict flood damage in urban areas (Seyoum et al. 2012). SWMM is suitable for urban flood modeling (Liu et al. 2014), although SWMM cannot forecast precisely as it does not have surface runoff routing (Jiang et al. 2015). Unlike SWMM, PCSWMM has improved the modeling of urban floods, which helps to better identify flood prone areas (Abdelrahman et al. 2018). PCSWMM can predict the effects of imperviousness on the hydrological characteristics of the catchment (Li Wang et al. 2018). In simulating urban flooding, spatial resolution of digital elevation models (DEM) and temporal resolution of hyetographs can affect model output (Abedin and Stephen 2015). Stream network modeling and quantification are also highly dependent on DEM resolution since the morphometric parameters of a stream network are dependent on DEM resolution (Paul et al. 2017).

LID practices have gained in popularity as an efficient method for stormwater management and have been applied successfully to various projects (Li, Deng et al. 2017; Kong et al. 2017). According to the US EPA, LID refers to systems and practices using or mimicking natural processes that result in the infiltration, evapotranspiration or use of stormwater in order to protect water quality and associated aquatic habitat (US EPA 2015). LID approaches are sometimes referred to as low impact urban design and development (LIUDD), best management practices (BMPs), sustainable urban drainage systems (SUDS), green infrastructure (GI), green stormwater infrastructure (GSI) or water sensitive urban design (WSUD) in different parts of the world (Fletcher et al. 2015).

LID approaches have been successfully used all over the world for stormwater management to improve water quality and hydrologic performance (Li, Yu et al. 2017). One study has found that an infiltration trench or a combination of an infiltration trench with a green roof can significantly reduce the volume of stormwater runoff (Joksimovic and Alam 2014). In another study, permeable pavement and bioretention cells both performed well in terms of reducing runoff (Lu and Yuan 2011). In addition to using individual LID components, sometimes a combination of several types can be more effective. LIDs, individual or in combination, are effective in small and medium scale rainfall events, but not very effective in heavy rainfall events (Li, Yu et al. 2017). SWMM–PCSWMM were efficient in simulating the impacts of LIDs in changing climate scenarios where precipitation data was used from the Coupled Model Intercomparison Project Phase 5 (CMIP5). The SWMM–PCSWMM model was modified according to a new proposed methodology that led to a reduction in runoff volume as well as a noticeable reduction in the peak flow rate in the final output (Zahmatkesh et al. 2015).

To successfully implement LID measures, it is initially required to find a suitable place to install the LID. ArcGIS is a well known software program for performing suitability analysis and handling a large amount of spatial data (Samanta et al. 2011; Kumar and Kumar 2014). In a GIS platform, it is possible to include several types of data as separate layers and assign importance to outputs by weighting with percentages. Both biophysical and programmatic criteria can be considered in a customized GIS model (Bhandaram n.d). In general, a suitability analysis is conducted based on predefined criteria. During the suitability analysis for green stormwater infrastructures such as bioretention cells, consideration of hydrologic principles could significantly improve output results. Sometimes model results for sustainable stormwater management can be exported into a decision support system (DSS). The spatial suitability analysis tool SSANTO, a GIS-based multi-criteria decision analysis tool, is a recent DSS addition that has produced good results in sustainable stormwater management initiatives. One unique feature of SSANTO is that it considers suitability from two perspectives (needs and opportunities), which has given this tool an edge over other DSSs (Kuller et al. 2019). SSANTO combines different criteria such as biophysical, socioeconomic, planning and governance (opportunities) with criteria relating to ecosystem services (needs). However, due to voluminous data requirements, SSANTO can sometimes be impossible to use or does not provide expected results when there is a lack of all necessary data.

From the preceding discussion, it is clear that PCSWMM has improved stormwater modeling and thereby stormwater management initiatives. The 2D mesh capability in PCSWMM has overwhelmingly improved stormwater modeling and flood risk mapping for urban areas. Over time, LID has gained in popularity as a sustainable measure of stormwater management with bioretention cells being the most effective LID, specifically when dealing with water quality issues. Although SSANTO could potentially be a good tool for suitability analysis for bioretention cells, due to data deficiency specific to SSANTO, this tool was removed from consideration.
3 Data and methods

3.1 Data requirements

Data requirements for each objective are described in this section.

Objective 1a of this study was to assess the capacity of the existing stormwater network. This task required a DEM of the study area, the existing stormwater network, and rainfall data. The DEM was produced using lidar data, which was collected from the GIS division of the City of Auburn. Existing stormwater network data was collected from the Facilities Management Division at Auburn University. There were two sources of rainfall data: design storm event data from the Natural Resources Conservation Service (NRCS) Technical Release 55 of the U.S. Department of Agriculture (USDA); and onsite rainfall data was collected through an installed rain gauge (Figure 6) on top of the Haley Center at Auburn University.

![Figure 6 Rain gauge installed on top of the Haley Center.](Rain gauge.jpg)

Objective 1b required a DEM of the study area since slope of an area can explain most of the water flow velocity. The data requirements for Objective 1a were enough to conduct analysis for Objective 2. Objective 3 required existing roads, waterbodies, soil types, parking lot locations, slope and structures data as a GIS layer. These were collected from the Auburn University Library GIS data portal.

3.2 Methodology

The methods for Objectives 1a, 1b, and 2 are described in Section A and the methods for Objective 3 are described in Section B.

Section A

Analysis for objectives 1a, 1b, and 2 was based on the same input data, so their methodologies have been presented together (Figure 7).

When the lidar data had been collected, a DEM was generated in ArcGIS. For the DEM, the existing storm sewer network map and field visit were the basis for subcatchment delineation. Though it would be possible to automatically delineate the subcatchment area based solely on the DEM in PCSWMM, for Objective 1b, in order to represent the existing stormwater network, the subcatchment delineation was performed in ArcGIS. The DEM raster file and subcatchment shape file were imported into PCSWMM. The DEM tool was used to determine the percentage of each subcatchment calculated in PCSWMM using the Set DEM Slope tool. Conduits and nodes present in computer aided design (CAD) files were initially converted into shape files and then imported into PCSWMM. Making the conduits and nodes layers as background and locking them together (for stability during drawing new layers within PCSWMM) formed the layer which was referenced to create the new conduits and nodes layer in PCSWMM. Areas for subcatchment were automatically calculated in PCSWMM and depth for nodes were defined as per the collected stormwater network map. Finally, conduit types and dimensions were correctly defined. After completing all these preliminary data processing tasks, a SWMM5 project was generated within PCSWMM, which was customized for our study area. Using NRCS Technical Release 55, a customized NRCS Type III, 10-y return period with a 24-h storm was designed in PCSWMM. The SWMM5 model was then run with designed storm event rainfall. In addition, a map with maximum water velocity was generated to identify areas where runoff water would flow rapidly or at a medium pace.

In the next stage (Objective 2), a few LID components (rainwater harvesting tanks, permeable pavements, and bioretention cells) were incorporated into the SWMM5 model as placing LIDs could potentially help to reduce erosion problems. With the LID components considered, the model was run again and compared with previous results to see any differences between them.

Section B

Objective 3 was to identify suitable places to install bioretention cells within the Auburn University campus. Taking into consideration suggestions made in relevant literature, bioretention cells seem to be the most appropriate stormwater management measure for this study. Using all the required data layers (as described in the data requirements section), a GIS model was developed in ArcGIS Model Builder to find suitable places for bioretention cell installation. The whole process is represented as a flowchart (Figure 8).
Data Collection
Data Preprocessing
Define Individual data Layers by Importance
Weighted Overlay
Using 'Con', 'Majority Filter', 'Select Layer by Attribute' Tools in ArcGIS
Final Suitable Site Selection

Figure 8 Simplified methodological framework for bioretention suitability for Objective 3.

When building the model in ArcGIS, several important parameters with specific considerations (Table 1) were examined to obtain the best possible output results.

Table 1 Specific considerations for data layers used for model building of bioretention suitability.

| Parameter | Restriction       | Weight | Score (1 to 5) |
|-----------|-------------------|--------|---------------|
| Slope     | NA                | 10     | <14: Score 5  |
|           |                   |        | 0–14: Score 3 |
| Road      | 0–15 ft           | 30     | 0: Score 1    |
|           |                   |        | 0–15 ft       |
| Structure | 0–20 ft           | 10     | Closer areas are more suitable than further areas. |
| Waterbody | 0–15 ft           | 10     | Closer areas are more suitable than further areas. |
| Parking Lot| NA                | 30     | Closer areas are more suitable than further areas. |
| Soil      | NA                | 10     | Marvyn loamy sand: 5 |
|           |                   |        | Pacolet sandy loam: 4 |
|           |                   |        | Marvyn–urban land complex: 3 |
|           |                   |        | Pacolet–urban land complex: 2 |
|           |                   |        | Urban land: 1 |

Column 2 (Restriction) in Table 1 refers to the areas excluded from the analysis. Although it is good to have bioretention cells closer to the road because of pollutants in road surfaces, in this study, a 15 ft (4.3 m) buffer zone around the road was excluded for future expansion and utility installations. Similarly, up to 20 ft (6 m) was excluded from existing structures since water accumulated in bioretention cells very close to structures could be a potential threat for foundational damage. Up to 15 ft (4.3 m) from waterbodies was also excluded so that there was less potential for water pollution. Parking lot and road layers were assigned the highest weight (30) as they are the main sources of runoff generation as well as pollutants. Plain areas (slope 0) were considered least suitable for bioretention cells as water is likely to be permanently stayed that area. Areas with a slope of 0–14% were considered best (score 5) for this study. Roads, structures, waterbodies, and parking lots were considered most suitable, and suitability decreased with an increase in distance. Loamy soil is more permeability, so it was assigned a score of 5. Consequently, other soil types were assigned lower scores due to less permeability. Predetermined weights for each individual layer were assigned using the Weighted Overlay tool.

With all the above criteria input, the model was run to generate the initial suitability map (scaled 1:5) for the Auburn University campus. Due to their relatively higher importance, areas with scores of 5 were extracted using the Con tool (conditional tool in ArcGIS, which is used for conditional query building) within the model environment. In order to obtain the most desired location and making the raster-based analysis more accurate, the Majority Filter tool was added in the model, using a value of 8. Replacement Threshold was Majority (5 out of 8 connected cells must have the same value) in the Majority Filter tool. The output raster was then converted into a polygon using the Raster to Polygon tool. Finally, in order to optimize area selection (selecting a larger chunk of area), the Select Layer by Attribute tool was added to the model with Selection Type as SUBSET_SELECTION and Expression as Area ≥50,000 ft².

4 Analysis and discussion

4.1 Analysis and discussion for Objective 1a

The DEM of an area is one of the most vital pieces of information required to generate a stormwater model (Leitao and de Sousa 2018; Yin et al. 2020). A high-resolution DEM was prepared for the study area instead of using a freely available low-resolution DEM. The existing stormwater network covers only the Auburn University campus area, but water drains in from the northern side of the campus too, adding to the surface runoff within campus. These facts were taken into consideration while preparing the DEM and the SWMMS project. With the necessary inputs (discussed in the ‘Data and Methods’ section), a SWMMS project was generated for the study area using PCSWMM. There are 26 subcatchments, 41 junctions, and 41 conduits in the customized model for the study area. To give a better understanding of the existing stormwater management scheme, Figure 9 shows the ‘Subcatchments’ as ‘S’ and locations of ‘Junction’ as ‘J’ on a ‘Google Earth’ image as back-drop generated from the PCSWMM model.
Another advantage of using PCSWMM is its predesigned rainfall data as well as the option of customizing primary rainfall data for an area. This feature has made simulating stormwater much easier for people without very deep knowledge of water modeling. Due to this customizing ability, NRCS ‘Technical Release -55’, Type III as well as 10-year storm event rainfall data (Figure 10) was customized for the Auburn area.

From the simulation, it was found that only 6 nodes were flooding (Table 2) and among them three nodes (J31, J38, J8) were more significantly flooded than others. This showed that there was no major issue causing flooding on Auburn University campus.

Flooding at the junctions is shown in Table 2. Flooding occurred for junctions 8, 31 and 38. The maximum flow rate for junction 31 (109.54 ft³/s, 3.10 m³/s) was considerably higher than others, and this location also has the largest flood volume (1.453 million gal., 5500 m³) for the assumed rainfall series.

Table 2 Summary of node flooding.

| Node | Hours Flooded | Maximum Rate (ft³/s) | Time of Max Occurrence | Total Flood Volume (10⁶ gal.) | Maximum Ponded Depth (ft) |
|------|---------------|----------------------|------------------------|-----------------------------|---------------------------|
| J31  | 0.75          | 109.54               | 0 12:00                | 1.453                       | 0.000                     |
| J38  | 0.22          | 72.63                | 0 12:00                | 0.333                       | 0.000                     |
| J8   | 0.75          | 42.59                | 0 12:00                | 0.399                       | 0.000                     |

Node surcharging is another important consideration when stormwater modeling and it occurs when water rises above the highest conduit connected or at grade elevation. Surcharging for J18 (Table 3) lasted for as long as 47 h, although the height above crown (top of outer edge) was relatively low (only 1.7 ft, 0.52 m). On the other hand, junctions J28 and J29 had a much larger increase in water depth, but relatively shorter duration, lasting <1 h.

Table 3 Summary of node surcharges.

| Node | Type     | Hours Surcharged | Max. Height Above Crown (ft) | Min. Depth Below Rim (ft) |
|------|----------|------------------|------------------------------|---------------------------|
| J10  | JUNCTION | 0.10             | 4.066                        | 2.234                     |
| 11   | JUNCTION | 0.30             | 5.700                        | 0.000                     |
| J12  | JUNCTION | 0.29             | 6.005                        | 3.995                     |
| J18  | JUNCTION | 47.02            | 1.686                        | 1.344                     |
| J28  | JUNCTION | 0.71             | 11.050                       | 0.000                     |
| J29  | JUNCTION | 0.78             | 9.294                        | 0.506                     |
| J30  | JUNCTION | 0.28             | 5.581                        | 4.719                     |
| J31  | JUNCTION | 0.77             | 6.800                        | 0.000                     |
| J38  | JUNCTION | 0.78             | 4.100                        | 0.000                     |
| J42  | JUNCTION | 0.22             | 2.800                        | 0.000                     |
| J5   | JUNCTION | 0.74             | 2.320                        | 6.680                     |
| J8   | JUNCTION | 0.77             | 6.400                        | 0.000                     |

4.2 Analysis and discussion for Objective 1b

Areas with higher velocity result in higher suspended load and eventual erosion. This vital information should be kept in mind while working on LID installation. A 2D mesh was generated to get water velocity from PCSWMM.

Three categories were defined, depending on water surface velocity: high velocity areas, where water surface velocity (calculated as maximum water velocity, MWV) MWV > 8.01 ft/s (2.44 m/s); medium velocity areas, with MWV 4 ft/s–8.01 ft/s (1.22
8 m/s–2.44 m/s); and low velocity areas, with MWV <4 ft/s (1.22 m/s). The final output was the MWV map for the study area (Figure 12).

Figure 12  MWV map of the study area. (Here arrow at the bottom left refers to the discharge point in Parkerson Mill Creek).

4.3 Analysis and discussion for Objective 2

Although there seems to be no major flooding issue within the Auburn University campus, stormwater management should still be considered in anticipation of unprecedented extreme rainfall events in the future.

Objective 2 was to investigate the benefits of LID installations. Table 4 shows the various LID types used in simulating hypothetical scenarios within the study area and their effects on stormwater runoff. The three most popular types of LIDs, rainwater harvesting, bioretention and permeable pavement (Table 4), were considered for this analysis. In total, about 14 957.39 m$^2$ will be covered by all the LID units.

Table 4 LID types considered for assessment of their impacts on stormwater management.

| Subcatchment | LID Type           | Number of Units | Unit Area (ft$^2$) |
|--------------|--------------------|-----------------|-------------------|
| S31          | Rainwater harvesting | 2               | 500               |
| S32          | Bioretention       | 1               | 20 000            |
| S34          | Permeable pavement | 3               | 5000              |
| S35          | Permeable pavement | 6               | 5000              |
| S37          | Permeable pavement | 5               | 5000              |
| S38          | Permeable pavement | 5               | 5000              |
| S49          | Permeable pavement | 4               | 5000              |
| S50          | Permeable pavement | 5               | 5000              |

Considering all the LID components, a new SWMM5 project was created in PCSWMM and run with NRCS 10-y storm event rainfall data. A comparison between the baseline scenarios (no LIDs) and the new project in terms of the hydrological performance, is shown in Table 5.

Table 5 Comparison of results of two models for the NRCS 10-y storm event.

| Hydrological Parameter                  | LID implemented | Baseline   |
|----------------------------------------|-----------------|------------|
| Max. subcatchment total runoff (10$^6$ gal.) | 5.64            | 5.71       |
| Max. subcatchment peak runoff (ft$^3$/s) | 148.45          | 148.78     |
| Num. nodes flooded                     | 5               | 6          |
| Max. node flood volume (10$^6$ gal.)    | 1.447           | 1.453      |
| Max. outfall flow frequency (%)        | 93.28           | 93.72      |
| Total outfall volume (10$^6$ gal.)      | 42.057          | 42.495     |
| Max. link flow (ft$^3$/s)              | 953.82          | 955.96     |
| Max. link peak velocity (ft/s)         | 47.48           | 47.51      |

When LIDs were considered, the number of nodes flooded decreased from 6 nodes to 5 nodes. Total outfall volume also decreased from 42.495 million gal. to 42.057 million gal. (193 186 m$^3$–191 195 m$^3$). There was also a decrease in the maximum link flow from 955.96 ft$^3$/s to 933.82 ft$^3$/s (27.1 m$^3$/s–27.0 m$^3$/s). These numbers might look insignificant, but they make sense as only a few LID components in some preselected subcatchments with limited capacity were considered for the preliminary analysis.

In addition to simulating with NRCS 10-y rainfall data, the other approach was to explore the efficiency of LIDs for a light rainfall event (onsite collection). The same two models were run using onsite gauged rainfall data collected on 2019-04-06. As this event was more moderate than the NRCS event, there were some noticeable improvements when LIDs were included in this model run, as shown in Table 6. The maximum outfall peak flow, total output volume, and the maximum link peak flow respectively decreased from 40.35 ft$^3$/s to 26.24 ft$^3$/s (1.14 m$^3$/s–0.74 m$^3$/s), from 0.475 million gal. to 0.369 million gal. (1798 m$^3$–1397 m$^3$), and from 40.35 ft$^3$/s to 26.24 ft$^3$/s (1.14 m$^3$/s–0.74 m$^3$/s).

Table 6 Comparison of results of two models for 2019-04-06 rainfall.

| Hydrological Parameter                  | LID implemented | Baseline   |
|----------------------------------------|-----------------|------------|
| Max. subcatchment total runoff (10$^6$ gal.) | 0.05            | 0.06       |
| Max. subcatchment peak runoff (ft$^3$/s) | 5.46            | 7.1        |
| Num. nodes flooded                     | 0               | 0          |
| Max. node flood volume (10$^6$ gal.)    | 0               | 0          |
| Max. outfall flow frequency (%)        | 41.99           | 46.78      |
| Total outfall volume (10$^6$ gal.)      | 0.369           | 0.475      |
| Max. link flow (ft$^3$/s)              | 26.24           | 40.35      |
| Max. link peak velocity (ft/s)         | 16.27           | 16.27      |

The reduction in volume, decrease in peak flow and other changes are additional benefits of installing LIDs; the primary benefit is improvement in surface water runoff quality. As long term flooding is currently not an issue for the Auburn University
campus, reduction in volume and peak flow could result in re-
ducing moderate flooding from milder rain events.

It can be easily said that LIDs are most effective in less in-
tense rainfall events. Auburn has experienced some major storms
in the past 10 years (In Case of Flooding—City of Auburn n.d.), so
LIDs will alleviate flooding. The Auburn University SWMPP put
great emphasis on improving the quality of surface water runoff
by reducing pollutant loading through the implementation of
LIDs (Stormwater Management Committee 2019).

4.4 Analysis and discussion for Objective 3

An extensive literature review and the environment of the study
area suggested that bioretention cells, which are one of the LIDs
considered in this study, could be most suitable for effective
stormwater management at Auburn University. Locating the most
suitable places for the installation of bioretention cells is very im-
portant to ensure optimum results. Objective 3 was intended to
find the most suitable sites for bioretention cell installation in the
study area. With all the necessary inputs and executing sequen-
tial procedures (described in section 2), a model was developed
in the ArcGIS Model Builder environment to produce the final
output for Objective 3 (Figure 13).

Figure 13 Most suitable areas (with score 5, colored red) for
bioretention cells.

Several areas within the Auburn University campus were
identified (Figure 13) as suitable sites for bioretention cell instal-
ation. Those areas were given a score of 5, which means most
suitable (the lower the score, the less suitable the location); they
are the only areas identified in Figure 13. Areas with lower suit-
ability scores (such as score 4 or 3) could be considered in future
stormwater management improvements.

5 Limitation and significance

The SWMM model has not yet been calibrated, as its creation is
relatively recent, so the results are more useful in terms of com-
parison between junctions and scenarios rather than for provid-
ing precise estimates of the hydraulic and hydrological behavior
of the system.

Another aspect of the research is simulation with only 10-y
rainfall. This preliminary study could not account other rainfall
types due to time constraints, but surely aiming to continue this
work for getting more accurate output in future. In future, work-
ing on it will be much easier, since then we do not have to work
from scratch.

6 Conclusion

Although the Auburn University campus is not prone to
prolonged flooding, due to lack of frequent intense storm events,
it is important to manage and implement an efficient stormwater
system in case of a future unexpected severe rainfall event. This
study highlights that LIDs, especially bioretention cells, will
address water pollution concerns in Parkerson Mill Creek through
screening. Bioretention cells will also create pervious surfaces,
which will increase the percolation of stormwater runoff,
ultimately recharging the groundwater. To leverage the already
existing stormwater management plan for the Auburn University
campus, simulations using PCSWMM were run to find the most
suitable locations for bioretention cells within the study area. If
these were implemented as identified, they would reduce peak
flow and total volume of stormwater, and screen off stormwater
pollutants. Thus, LIDs can be helpful for managing stormwater in
sustainable way.

Acknowledgments

The authors express their gratitude to the Auburn University
Facilities Management Division for providing stormwater network
data as well as other support.

Disclosure Statement

There is no potential conflict of interest among the authors.

References

Abdelrahman, Y.T., A.M. El Moustafa, and M. Elfawy. 2018.
“Simulating Flood Urban Drainage Networks through
1D/2D Model Analysis.” Journal of Water Management
Modeling 26: C454. https://doi.org/10.14796/JWMM.C454

Abedin, S., J. Hossain, and S. Haroon. 2015. “Relating DEM
Spatial Resolution and Hyetograph Temporal Resolution to
Flood Modeling Accuracy.” In World Environmental and
Water Resources Congress 2015, 2607–16. Austin, TX:
American Society of Civil Engineers.
https://doi.org/10.1061/9780784479162.256

Adams, B.J. 2000. “Urban Stormwater Management Planning with
Analytical Probabilistic Models.”
https://www.osti.gov/biblio/20051022

“Auburn at a Glance.” 2019. Auburn University. 2019.
http://www.auburn.edu
Barbosa, A.E., J.N. Fernandez, and L.M. David. 2012. “Key Issues for Sustainable Urban Stormwater Management.” Water Research 46 (20): 6787–98. https://doi.org/10.1016/j.watres.2012.05.029

Barco, J., K.M. Wong, and M.K. Stenstrom. 2008. “Automatic Calibration of the U.S. EPA SWMM Model for a Large Urban Catchment.” Journal of Hydraulic Engineering 134 (4): 466–74. 34:4(466) https://doi.org/10.1061/(ASCE)0733-9429(2008)134:4(466)

Berland, A., and M.E. Hopton. 2014. “Comparing Street Tree Assemblages and Associated Stormwater Benefits among Communities in Metropolitan Cincinnati, Ohio, USA.” Urban Forestry & Urban Greening 13 (4): 734–41. https://doi.org/10.1016/j.ufug.2014.06.004

Bhandaram, U. n.d. “GIS and Green Infrastructure: Case Study in the Alley Creek Watershed and Sewershed, Queens, New York.” New Haven, CT: Yale University. Accessed June 2020. https://www.fs.fed.us/nrs/nyc/slc/local-resources/docs/Bhandaram_finalreport.pdf

Bohman, A., E. Glaas, and M. Karlson. 2020. “Integrating Sustainable Stormwater Management in Urban Planning: Ways Forward towards Institutional Change and Collaborative Action.” Water 12 (1): 203. https://doi.org/10.3390/w12010203

Christianson, R.D., B.J. Barfield, J.C. Hayes, K. Gaesem, and G.O. Brown. 2004. “Modeling Effectiveness of Bioretention Cells for Control of Stormwater Quantity and Quality.” In Critical Transitions in Water and Environmental Resources Management, 1–7. Salt Lake City, UT: American Society of Civil Engineers. https://doi.org/10.1061/40737(2004)37

Davis, A.P. 2005. “Green Engineering Principles Promote Low-Impact Development.” Environmental Science & Technology 39 (16): 338A–344A. https://doi.org/10.1021/es0503327e

Davis, A.P., W.F. Hunt, R.G. Traver, and M. Clar. 2009. “Bioretention Technology: Overview of Current Prac-tice and Future Needs.” Journal of Environmental Engineer-ing 135 (3): 109–17. https://doi.org/10.1061/(ASCE)0733-9372(2009)135:3(109)

Denchak, M. 2019. “Green Infrastructure: How to Manage Water in a Sustainable Way.” NRDC. https://www.nrdc.org/stories/green-infrastructure-how-manage-water-sustainable-way

Dongquan, Z., C. Jining, W. Haozheng, T. Qingyuan, C. Shangbing, and Z. Sheng. 2009. “GIS-Based Urban Rainfall-Runoff Modeling Using an Automatic Catchment-Discretization Approach: A Case Study in Macau.” Environmental Earth Sciences 59 (2): 465–72. https://doi.org/10.1007/s12665-009-0045-1

Fletcher, T.D., W. Shuster, W.F. Hunt, R. Ashley, D. Butler S. Arthur, S. Trowsdale, et al. 2015. “SUDS, LID, BMPs, WSUD and More – The Evolution and Application of Terminology Surrounding Urban Drainage.” Urban Water Journal 12 (7): 525–42. https://doi.org/10.1080/1573062X.2014.916314

Hall, A. 2015. “Bioretention.” Cape Cod Green Infrastructure Guide (blog): February 27, 2015. https://www.nrdc.org/stories/green-infrastructure-in-a-sustainable-way

In Case of Flooding—City of Auburn. n.d. Accessed June 11, 2020. https://www.auburnalabama.org/engineering-services/flood-protection/in-case-of-flooding/

Imran, H.M., S. Akib, and M.R. Karim. 2013. “Permeable Pavement and Stormwater Management Systems: A Review.” Environmental Technology 34 (18): 2649–56. https://doi.org/10.1080/09593330.2013.782573

Jiang, L., Y. Chen, and H. Wang. 2015. “Urban Flood Simulation Based on the SWMM Model.” Proceedings of the International Association of Hydrological Sciences 368 (May): 186–91. https://doi.org/10.5194/iahs-368-186-2015

Joksimovic, D., and Z. Alam. 2014. “Cost Efficiency of Low Impact Development (LID) Stormwater Management Practices.” In Procedia Engineering, 16th Water Distribution System Analysis Conference, WDSA2014, 89 (January), 734–41. https://doi.org/10.1016/j.proeng.2014.11.501

Johnson, C. 2012. Examination of the Effectiveness of Bioretention Cells and Porous Paving Practices in Aiken, SC. Clemson, SC: Clemson University. Master’s thesis.

Kabbani, M.S. 2015. “Using PCSWMM to Simulate First Flush and Assess Performance of Extended Dry Detention Ponds as Structural Stormwater BMPs in a Large Polluted Urban Watershed.” Iowa City, IA: University of Iowa. PhD dissertation. https://doi.org/10.17077/etd.bwybamwp

Kaspersen, P., R. Fensholt, and M. Drews. 2015. “Using Landsat Vegetation Indices to Estimate Impervious Surface Fractions for European Cities.” Remote Sensing 7 (6): 8224–49. https://doi.org/10.3390/rs70608224

Kong, F., Y.B. H. Yin, P. James, and I. Dronova. 2017. “Modeling Stormwater Management at the City District Level in Response to Changes in Land Use and Low Impact Development.” Environmental Modelling &
Larsen, T. 2013. “A High Resolution Application of a Stormwater Management Model (SWMM) Using Genetic Parameter Optimization.” *Urban Water Journal* 10 (6): 394–410. https://doi.org/10.1080/1573062X.2012.739631

Kuller, M., P.M. Bach, S. Roberts, D. Browne, and A. Deletic. 2019. “A Planning-Support Tool for Spatial Suitability Assessment of Green Urban Stormwater Infra-structure.” *Science of The Total Environment* 686 (October): 856–68. https://doi.org/10.1016/j.scitotenv.2019.06.051

Kumar, S., and R. Kumar. 2014. “Site Suitability Analysis for Urban Development of a Hill Town Using GIS Based Multicriteria Evaluation Technique: A Case Study of Nahang Town, Himachal Pradesh, India.” *International Journal of Advanced Remote Sensing and GIS*, 3 (1): 516–24.

Leitão, J.P., and L.M. de Sousa. 2018. “Towards the Optimal Fusion of High-Resolution Digital Elevation Models for Detailed Urban Flood Assessment.” *Journal of Hydrology* 561 (June): 651–61. https://doi.org/10.1016/j.jhydrol.2018.04.043

Li, J., C. Deng, Y. Li, Y. Li, and J. Song. 2017. “Comprehensive Benefit Evaluation System for Low-Impact Development of Urban Stormwater Management Measures.” *Water Resources Management* 31 (15): 4745–58. https://doi.org/10.1007/s11269-017-1776-5

Li, N., Q. Yu, J. Wang, and X. Du. 2017. “The Effects of Low Impact Development Practices on Urban Stormwater Management.” In *International Low Impact Development Conference China 2016, Proceedings*, 12–20. https://doi.org/10.1061/9780784481042.002

Liu, J., D. Sample, C. Bell, and Y. Guan. 2014. “Review and Research Needs of Bioretention Used for the Treatment of Urban Stormwater.” *Water* 6 (4): 1069–99. https://doi.org/10.3390/w6041069

Liwanag, F., D.S. Mostrales, Ma. T.T. Ignacio, and J.N. Orejudos. 2018. “Flood Modeling Using GIS and PCSWMM.” *Engineering Journal* 22 (3): 279–89. https://doi.org/10.4186/ej.2018.22.3.279

Lu, P., and T. Yuan. 2011. “Low Impact Development Design for Urban Stormwater Management—A Case Study in USA.” In 2011 *International Symposium on Water Resource and Environmental Protection*, 4: 2741–44. https://doi.org/10.1109/ISWREP.2011.5893446

Marlow, D.R., M. Moglia, S. Cook, and D.J. Beale. 2013. “Towards Sustainable Urban Water Management: A Critical Reassessment.” *Water Research* 47 (20): 7150–61. https://doi.org/10.1016/j.watres.2013.07.046

Niazi, M., C. Nieto, M. Maghreb, N. Jackson, B.R. Bennett, Michael Tryby, and Arash Massoudieh. 2017. “Storm Water Management Model: Performance Review and Gap Analysis.” *Journal of Sustainable Water in the Built Environment* 3 (2): 04017002. https://doi.org/10.1061/JSWBAY.0000817

Obropta, C.C., and J.S. Kardos. 2007. “Review of Urban Stormwater Quality Models: Deterministic, Stochastic, and Hybrid Approaches 1: Review of Urban Stormwater Quality Models: Deterministic, Stochastic, and Hybrid Approaches.” *JAWRA Journal of the American Water Resources Association* 43 (6): 1508–23. https://doi.org/10.1111/j.1752-1688.2007.00124.x

Paul, D., V.R. Mandla, and T. Singh. 2017. “Quantifying and Modeling of Stream Network Using Digital Elevation Models.” *Ain Shams Engineering Journal* 8 (3): 311–21. https://doi.org/10.1016/j.asej.2015.09.002

Paule-Mercado, M.A., B.Y. Lee, S.A. Memon, S.R. Umer, I. Salim, and C.H. Lee. 2017. “Influence of Land Development on Stormwater Runoff from a Mixed Land Use and Land Cover Catchment.” *Science of The Total Environment* 599–600 (December): 2142–55. https://doi.org/10.1016/j.scitotenv.2017.05.081

Rossman, L.A. 2015. “Storm Water Management Model User’s Manual Version 5.1.” U.S. Environmental Protection Agency.

Samanta, S. B. Pal, and D.K. Pal. 2011. “Land Suitability Analysis for Rice Cultivation Based on Multi-Criteria Decision Approach through GIS.” *International Journal of Science & Emerging Technologies* 2 (1). http://ojs.excellingtech.co.uk/index.php/JSET/article/view/270

Seymour, S.D., Z. Vojinovic, R.K. Price, and S. Weesakul. 2012. “Coupled 1D and Noninertia 2D Flood Inundation Model for Simulation of Urban Flooding.” *Journal of Hydraulic Engineering* 138 (1): 23–34. https://doi.org/10.1061/(ASCE)HY.1943-7900.0000485

“Storm Water Management Model | U.S. Climate Resilience Toolkit”. 2019. U.S. Environmental Protection Agency. https://toolkit.climate.gov/tool/storm-water-management-model

Stormwater Management Committee, Auburn University. 2019. *Auburn University Stormwater Management Program Plan*. https://cws.auburn.edu/shared/files?id=227&filename=Appendix%20D%20SWMPP%20May%202019%20final.pdf

Tikkanen, H. 2013. *Hydrological Modeling of a Large Urban Catchment Using a Stormwater Management Model (SWMM).* Espoo, Finland: Aalto University. https://aaltodoc.aalto.fi/handle/123456789/27496
US EPA. 2014. *Storm Water Management Model (SWMM)*. Data and Tools. Washington, DC: U.S. Environmental Protection Agency. https://www.epa.gov/water-research/storm-water-management-model-swmm

US EPA. 2015. *Urban Runoff: Low Impact Development*. Washington, DC: U.S. Environmental Protection Agency. Overviews and Factsheets. https://www.epa.gov/nps/urban-runoff-low-impact-development

Wang, J., L. Zhao, C. Zhu, and B. Shi. 2018. “Review and Optimization of Carrying Capacity of Urban Drainage System Based on ArcGIS and SWMM Model.” In *Advances in Hydroinformatics*, edited by Philippe Gourbes-ville, Jean Cuneg and Guy Caignaert, 719–26. Singapore: Springer Singapore. https://doi.org/10.1007/978-981-10-7218-5_51

Xu, Z., L. Xiong, H. Li, J. Xu, X. Cai, K. Chen, and J. Wu. 2019. “Runoff Simulation of Two Typical Urban Green Land Types with the Stormwater Management Mod-el (SWMM): Sensitivity Analysis and Calibration of Runoff Parameters.” *Environmental Monitoring and Assessment* 191 (6): 343. https://doi.org/10.1007/s10661-019-7445-9

Yang, X., W. Yue, H. Xu, J. Wu, and Y. He. 2014. “Environmental Consequences of Rapid Urbanization in Zhejiang Province, East China.” *International Journal of Environmental Research and Public Health* 11 (7): 7045–59. https://doi.org/10.3390/ijerph110707045

Yao, L., L. Chen, and W. Wei. 2017. “Exploring the Linkage between Urban Flood Risk and Spatial Patterns in Small Urbanized Catchments of Beijing, China.” *International Journal of Environmental Research and Public Health* 14 (3). https://doi.org/10.3390/ijerph14030239

Yin, D., B. Evans, Q. Wang, Z. Chen, H. Jia, A.S. Chen, G. Fu, S. Ahmad, and L. Leng. 2020. “Integrated 1D and 2D Model for Better Assessing Runoff Quantity Control of Low Impact Development Facilities on Community Scale.” *Science of The Total Environment* 720 (June): 137630. https://doi.org/10.1016/j.scitotenv.2020.137630

Zahmatkesh, Z., M. Karamouz, E. Goharian, and S.J. Burian. 2015. “Analysis of the Effects of Climate Change on Urban Storm Water Runoff Using Statistically Downscaled Precipitation Data and a Change Factor Approach.” *Journal of Hydrologic Engineering* 20 (7): 05014022. https://doi.org/10.1061/(ASCE)HE.1943-5584.0001064

Zhang, H., J. Cheng, Z. Wu, C. Li, J. Qin, and T. Liu. 2018. “Effects of Impervious Surface on the Spatial Distribution of Urban Waterlogging Risk Spots at Multiple Scales in Guangzhou, South China.” *Sustainability* 10 (5): 1589. https://doi.org/10.3390/su10051589

Zhou, Z., J.A. Smith, L. Yang, M.L. Baeck, M. Chaney, M-C. Ten Veldhuis H. Deng, and S. Liu. 2017. “The Complexities of Urban Flood Response: Flood Frequency Analyses for the Charlotte Metropolitan Region.” *Water Resources Research* 53 (8): 7401–25. https://doi.org/10.1002/2016WR019997

Zhu, J. 2010. “GIS Based Urban Flood Inundation Modeling.” In *2010 Second WRI Global Congress on Intelligent Systems*, 140–43. Wuhan, Hubei, China: IEEE. https://doi.org/10.1109/GCIS.2010.264