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.

![Figure 1 Aubu...](image)

![Figure 2 NDVI map of Auburn University.](image)

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 3 Common permeable pavement systems (Imran et al. 2013).](image)
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.](image)

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 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).

![Figure 7 Methodological framework for Objectives 1a, 1b, and 2.](image)

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. Slope percentage for each subcatchment was 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 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).
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.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Restriction</th>
<th>Weight</th>
<th>Score (1 to 5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slope</td>
<td>NA</td>
<td>10</td>
<td>0: Score 1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0–14: Score 3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>&lt;14: Score 5</td>
</tr>
<tr>
<td>Road</td>
<td>0–15 ft</td>
<td>30</td>
<td>Closer areas are more suitable than further areas.</td>
</tr>
<tr>
<td>Structure</td>
<td>0–20 ft</td>
<td>10</td>
<td>Closer areas are more suitable than further areas.</td>
</tr>
<tr>
<td>Waterbody</td>
<td>0–15 ft</td>
<td>10</td>
<td>Closer areas are more suitable than further areas.</td>
</tr>
<tr>
<td>Parking Lot</td>
<td>NA</td>
<td>30</td>
<td>Closer areas are more suitable than further areas.</td>
</tr>
<tr>
<td>Soil</td>
<td>NA</td>
<td>10</td>
<td>Marvyn loamy sand: 5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Pacolet sandy loam: 4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Marvyn–urban land complex: 3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Pacolet–urban land complex: 2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Urban land: 1</td>
</tr>
</tbody>
</table>

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.

Figure 10 NRCS Type III, 10-y return period storm event rainfall time series (Y-axis refers to Precipitation (inches)).

The 10-y return period simulated storm principally showed potential flooding (indicated as red in Figure 11).

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.

<table>
<thead>
<tr>
<th>Node</th>
<th>Hours Flooded</th>
<th>Maximum Rate (ft³/s)</th>
<th>Time of Max Occurrence</th>
<th>Total Flood Volume (10⁶ gal.)</th>
<th>Maximum Ponded Depth (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>J31</td>
<td>0.75</td>
<td>109.54</td>
<td>0 12:00</td>
<td>1.453</td>
<td>0.000</td>
</tr>
<tr>
<td>J38</td>
<td>0.22</td>
<td>72.63</td>
<td>0 12:00</td>
<td>0.333</td>
<td>0.000</td>
</tr>
<tr>
<td>J8</td>
<td>0.75</td>
<td>42.59</td>
<td>0 12:00</td>
<td>0.399</td>
<td>0.000</td>
</tr>
</tbody>
</table>

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.

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

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).

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 m² will be covered by all the LID units.

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

<table>
<thead>
<tr>
<th>Subcatchment</th>
<th>LID Type</th>
<th>Number of Units</th>
<th>Unit Area (ft²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S31</td>
<td>Rainwater harvesting</td>
<td>2</td>
<td>500</td>
</tr>
<tr>
<td>S32</td>
<td>Bioretention</td>
<td>1</td>
<td>20,000</td>
</tr>
<tr>
<td>S34</td>
<td>Permeable pavement</td>
<td>3</td>
<td>5000</td>
</tr>
<tr>
<td>S35</td>
<td>Permeable pavement</td>
<td>6</td>
<td>5000</td>
</tr>
<tr>
<td>S37</td>
<td>Permeable pavement</td>
<td>5</td>
<td>5000</td>
</tr>
<tr>
<td>S38</td>
<td>Permeable pavement</td>
<td>5</td>
<td>5000</td>
</tr>
<tr>
<td>S49</td>
<td>Permeable pavement</td>
<td>4</td>
<td>5000</td>
</tr>
<tr>
<td>S50</td>
<td>Permeable pavement</td>
<td>5</td>
<td>5000</td>
</tr>
</tbody>
</table>

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.

<table>
<thead>
<tr>
<th>Hydrological Parameter</th>
<th>LID implemented</th>
<th>Baseline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max. subcatchment total runoff (10⁶ gal.)</td>
<td>5.64</td>
<td>5.71</td>
</tr>
<tr>
<td>Max. subcatchment peak runoff (ft³/s)</td>
<td>148.45</td>
<td>148.78</td>
</tr>
<tr>
<td>Num. nodes flooded</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>Max. node flood volume (10⁶ gal.)</td>
<td>1.447</td>
<td>1.453</td>
</tr>
<tr>
<td>Max. outfall flow frequency (%)</td>
<td>93.28</td>
<td>93.72</td>
</tr>
<tr>
<td>Total outfall volume (10⁶ gal.)</td>
<td>42.057</td>
<td>42.495</td>
</tr>
<tr>
<td>Max. link flow (ft³/s)</td>
<td>953.82</td>
<td>955.96</td>
</tr>
<tr>
<td>Max. link peak velocity (ft/s)</td>
<td>47.48</td>
<td>47.51</td>
</tr>
</tbody>
</table>

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 m³–191.195 m³). There was also a decrease in the maximum link flow from 955.96 ft³/s to 935.82 ft³/s (27.1 m³/s–27.0 m³/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 ft³/s to 26.24 ft³/s (1.14 m³/s–0.74 m³/s), from 0.475 million gal. to 0.369 million gal. (1798 m³–1397 m³), and from 40.35 ft³/s to 26.24 ft³/s (1.14 m³/s–0.74 m³/s).

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

<table>
<thead>
<tr>
<th>Hydrological Parameter</th>
<th>LID implemented</th>
<th>Baseline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max. subcatchment total runoff (10⁶ gal.)</td>
<td>0.05</td>
<td>0.06</td>
</tr>
<tr>
<td>Max. subcatchment peak runoff (ft³/s)</td>
<td>5.46</td>
<td>7.1</td>
</tr>
<tr>
<td>Num. nodes flooded</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Max. node flood volume (10⁶ gal.)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Max. outfall flow frequency (%)</td>
<td>41.99</td>
<td>46.78</td>
</tr>
<tr>
<td>Total outfall volume (10⁶ gal.)</td>
<td>0.369</td>
<td>0.475</td>
</tr>
<tr>
<td>Max. link flow (ft³/s)</td>
<td>26.24</td>
<td>40.35</td>
</tr>
<tr>
<td>Max. link peak velocity (ft/s)</td>
<td>16.27</td>
<td>16.27</td>
</tr>
</tbody>
</table>

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, stormwater management is considered in the future.
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, working 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

https://doi.org/10.14796/JWMM.C454

https://doi.org/10.1061/9780784479162.256

https://www.osti.gov/biblio/20051022

http://www.auburn.edu


