Stormwater Management for a Healthier Campus Watershed:

The Value-Add of Green Stormwater and Watershed Management to the University of Richmond’s Campus Landscape

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Abstract

Increasing competitiveness, educational opportunities and available funding, investment in sustainable infrastructure can be an immense value-add to the modern-day college campus. This paper explores the use of green low impact development to mitigate the effects of stormwater runoff on the University of Richmond (UR) campus. Rich in sediment, nutrients, heavy metals, bacteria and other organic matter, stormwater runoff is one of the main non-point sources of pollution in urban water bodies and a key area of opportunity for UR to improve stewardship to the nearby James River. A review of academic and industry literature was conducted to determine whether or not a comprehensive watershed management plan which employs the use of green stormwater infrastructure would be a value add to the University of Richmond campus. Results indicate that by effectively reducing stormwater volume and pollution loads, LID has the potential to reduce UR’s environmental footprint and operating costs, while increasing educational opportunities. Results also support the installation of a vegetative buffer around the Westhampton Lake, rainwater harvesting facilities, permeable pavement, and bioretention basins on UR’s campus. The findings of this study have implications on the valuation of sustainable infrastructure in higher education and conceptualization of water management issues in the modern-day urban watershed.
1. Introduction

Land use modifications associated with urbanization (e.g. the removal of vegetation and replacement of pervious areas with impervious surfaces) change the natural drainage patterns of a landscape, increasing stormwater runoff volumes and peak water flows into nearby water bodies (Barbosa, Fernandes & David, 2012). This increased runoff has serious implications on water quality within the receiving water bodies as activities within urban areas often produce waste and pollutants which can be carried away in stormwater. Rich in sediment, nutrients, heavy metals, bacteria and other organic matter, stormwater runoff is one of the main non-point sources of pollution in urban water bodies (Barbosa, Fernandes & David, 2012).

In natural environments, stormwater either falls directly into larger water bodies or infiltrates into porous soil and rock layers. When stormwater is absorbed into the soil, it is filtered and ultimately used to replenish groundwater aquifers or flows into rivers and streams (EPA, 2013). Contrarily, in more urban areas, the high density of impervious surfaces, such as roofs and pavement, prevents the natural absorption of stormwater into the ground. Instead, stormwater rapidly travels through “grey infrastructure” – storm drains, concrete channels and pipes– out of the developed area.

Green infrastructure, also known as low impact development (LID), uses vegetation, soils and water retention methods to mimic the natural processes required to manage rainwater and create a healthy environment; examples of LIDs include bioswales, rainwater retention tanks, green roofs, and permeable surfacing (Damodaram et al., 2010). By reducing the flow rate of stormwater to water bodies and removing some of the pollutants from the water, LIDs help to reduce flood events, decrease water pollution and maintain healthy aquatic habitats.

Both comparison and simulation studies indicate that LID technologies are able to significantly reduce stormwater runoff during short-duration storms (Damodaram et al., 2010). In their comparisons of neighbourhoods designed using LID practices (including cluster development, bioretention, permeable pavement, reduced amounts of impervious area and bioswales) to traditionally developed neighbourhoods, Hood et al. (2007) and Dietz & Clausen (2008) both found that LID neighbourhoods had lower peak discharges, runoff coefficients, runoff volumes, and increased times to peak than traditionally developed neighbourhoods. Similar results were found in simulation studies where bioswales (Williams and Wise, 2006); rain gardens (Brander et al., 2004); rainwater harvesting (Sample and Heaney, 2006; Gilroy and McCuen, 2009); and other LID combinations (Xiao et al., 2007) were found to be effective stormwater controls during small storms.
Reducing stormwater volume, peak discharges and pollution loads can have major impacts on the overall health of a waterbody. As a non-point source of pollution, stormwater runoff encourages the conceptualization of water quality issues on a catchment-level scale, increasing opportunities to work with geomorphic processes and across socio-political boundaries to enhance the possible suite of results (Vietz et al., 2016). For example, Vietz et al. (2016) contend that urban stream restoration may be more successful if conceptualized on a catchment-level scale. According to Vietz et al. (2016), by both planning for catchment-level disturbances (e.g. stormwater) within the stream and focusing on interventions at the catchment-level which can ultimately contribute to stream health, catchment-level analysis addresses the root causes of channel degradation, increasing the overall chances of success.

In March 2019, construction began to restore the natural hydrological processes of the lower portions of Little Westham Creek (LWC), the main body of water flowing through the University of Richmond (UR) campus (Kent, 2019). With the primary goal of reducing nitrogen, phosphorus and sediment loads to the Chesapeake Bay, the 2,500 linear ft stream restoration project widened the creek’s floodplain to reduce polluted stormwater runoff to the James River during large rain events (Kent, 2019). Mitigating the effects of stormwater runoff in small events, LID complements stream restoration and can be used to advance sustainability initiatives at UR.

In addition to reaping positive environmental benefits, stormwater management represents a nexus of universities’ commitments to education, scholarship and service (Welker, Wadzuk & Traver, 2010). Using examples from Villanova University, Welker, Wadzuk & Traver (2010) maintain that stormwater management initiatives on college campuses can create avenues for student research projects, community engagement initiatives and civic-minded conversations about environmental stewardship.

As an “intentional community” the university campus is a place which has been physically and socially constructed to foster “discourse, debate, collaboration and social interaction” (Way et al, 2012, p. 27; Project for Public Spaces, 2018). Embedding green infrastructure elements in campus design can, therefore, not only increase the environmental services on campus but also establish environmental stewardship and sustainability as integral components of everyday learning and interaction (Way et al, 2012). Furthermore, according to Way et al. (2012), “incorporating sustainable infrastructure into the planning and renewal of a campus landscape potentially broadens the landscape’s value to the campus community as a teaching tool, for fund-raising opportunities, and for potentially realizing operations and maintenance savings by means of reduced use of water, energy and other additives” (p. 45).

A visible demonstration of a university’s commitment to environmental issues, sustainable infrastructure can also make a university more attractive to prospective students (Way et al.,
In response to the Princeton Review’s (2019) College Hopes & Worries Survey, 64% of students applying to college said that a college’s commitment to environmental issues would contribute to their decision to apply to or attend a school. Previous studies, therefore, suggest that by placing UR ahead of its peer institutions on sustainability issues, decreasing campus operating costs, providing means for place-based education, and complementing ongoing sustainability initiatives, green LID—as a form of sustainable infrastructure—has the ability to broaden the value of UR’s campus landscape. This paper summarizes a study to investigate if a comprehensive watershed management plan which includes the use of low impact development to mitigate the effects of stormwater runoff can increase the value of UR’s campus landscape. A review of past research and literature relevant to stormwater runoff and water quality management on university campuses was conducted to (a) determine how UR’s stormwater/watershed management policies compared to similar institutions and (b) identify effective and viable stormwater management strategies for the UR campus watershed.

2. Methodology

2.1 Site Description

The University of Richmond is a private liberal arts university in Richmond, VA. Founded in 1830, the University relocated to its current location in the West End of Richmond, VA in 1914, expanding over more than 100 years to its current size (UR History, n.d.). At the time of this study, the majority of the campus was situated in the city of Richmond, VA with small sections located in neighbouring Henrico County.

Since 2006, the UR campus has expanded significantly with the construction of at least nine, high-impact residential and academic complexes: Student Activities Center, Gateway Village, Weinstein Center for Recreation and Wellness, Carole Weinstein International Center, The Robins Stadium, Queally Center, Queally Hall, Lakeview Hall and Westhampton Hall etc (UR History, n.d.). By 2014, approximately 34% of the campus was covered with impervious ground cover and buildings (Fig. 1). The sprawl of campus has increased the overall percentage of impervious land cover and, subsequently, increased stormwater runoff into Little Westham Creek (LWC). By author calculations, since 2014 has paid over $150,000 in stormwater fees to the Richmond Department of Public Utilities (n.d.) annually.

A part of the James River Watershed, water quality and quantity in LWC have implications on the overall health of both the James River and the Chesapeake Bay (Fig. 2). In recognition of the impacts of campus watershed management on the James River and beyond, in 2011 the
University put out a request for proposals for consultation on a draft watershed management plan which included green low infrastructure development and other mechanisms to improve water quality in the lower LWC (University of Richmond, 2011). In 2014 and 2015, several Environmental Studies capstone projects captured the feasibility of mitigating stormwater runoff at UR and the implications it would have on water quality and resiliency within the campus watershed (Ahnell, Nuñez & Rathlev, 2014; Alderbashi, Collins & Wilkes, 2014; Holden, 2015).

In order to increase stewardship to the James River, UR’s Sustainability Plan (2019b) underscored the need to reduce stormwater impacts and develop a comprehensive water management plan for the campus. These goals aligned with UR’s most recent Strategic Plan (University of Richmond 2017), in which environmental stewardship was a primary pillar, and were analogous to the City of Richmond’s overall water quality and stormwater management goals outlined in the RVA Clean Water Plan (RVA H2O, 2017).

At the time of study, the on-campus stormwater system consisted mostly of grey stormwater infrastructure with underground retention pipes that pour primarily into The Westhampton Lake (Fig. 3). Therefore, the 42 million gallon Westhampton Lake, where pollution loaded sediment is allowed to settle out of stormwater, was used as a BMP for the majority of campus stormwater (University of Richmond, 2019a; S. Glass, personal communication, May 2, 2016). Areas not draining to the lake were addressed with bioswales.

2.2 Data Summary

To evaluate UR’s rainwater and watershed management performance compared to other universities, a list of 30 peer institutions was obtained from UR’s Office of Institutional Effectiveness (2010). These institutions were selected based on their comparability to UR in size, scope and resources.

Performance comparisons were made based on the publically-accessible STARS™ Reports submitted by UR and its peer institutions, which have a section to report rainwater management strategies. The Sustainability Tracking, Assessment & Rating System (STARS™) is a self-reporting framework by the Association for the Advancement of Sustainability in Higher Education (AASHE) for colleges and universities to measure their sustainability performance. Information from the STARS Reports was supplemented, when necessary, with a web search for sustainability initiatives at the institution in question.

While some information on UR’s rainwater management strategy was gleaned from its STARS™ report, most data for UR were obtained from University archives. Four professional watershed management proposals previously addressed to the University were received from Dr
Todd Lookingbill (Table 1). Student proposals for stormwater interventions on campus were gathered using the Online Scholarship Repository (Table 2).

All geospatial data and information pertaining to land use on UR’s campus were retrieved from the Spatial Analysis Lab (SAL) archives and UR’s ArcGis Online Portal. Land cover estimates used were based on land cover classification of UR’s campus according to an automated feature extraction rule set output from eCognition downloaded from ArcGIS Online. Extracted polygons were based on 1-meter resolution imagery from a 2014 NAIP dataset.

Precipitation frequency estimates from NOAA's Precipitation Frequency Data Server (PFDS) (Office of Water Prediction, 2017) were used to define the parameters for the design storm and calculate typical stormwater runoff from the UR campus.

For the evaluation of BMP efficacy, performance data for various BMPs were based on summary statistics from the International Stormwater BMP Database (International Stormwater BMP Database, 2017; International Stormwater BMP Database, 2011). Relative per cent volume reductions for each of the BMPs in question were calculated by Geosyntec Consultants & Wright Water Engineers, Inc. based on databases from hundreds of BMP studies throughout the U.S. and several other countries (BMP Database, 2011). The median values were used for this study. BMP performance with regard to pollution reduction was taken from the 2016 BMP Performance Database (BMP Database, 2017).

2.3 Data Analysis

Using the listed addresses for campus admissions offices, the 30 peer institutions were georeferenced using Geocodio’s online geocoding platform and then uploaded into ArcGIS Pro for further processing. Because every watershed is unique, the Select by Location tool was used to identify only institutions within the Chesapeake Bay watershed which are assumed to have similar hydrologic conditions and stormwater management goals as UR.

The self-submitted STARS Reports from all of the universities within the Chesapeake Bay watershed were then reviewed to determine whether or not the peer institutions had stormwater or watershed management plans. The STARS reports were also analyzed to identify if other universities in the watershed utilized some form of green stormwater infrastructure on their campus.

To identify key areas of opportunity in the development of a stormwater or watershed management plan for UR, previous proposals for consultation on a watershed management plan (Table 1) were analyzed based on their fulfilment of the University’s four main evaluation criteria: water quality improvement; cost-effectiveness; long-term savings; and green stormwater
infrastructure that addresses water, soils, vegetation, habitat, maintenance, aesthetics and the campus community (University of Richmond, 2011). Mention of various stormwater management practices was recorded and compared to the University’s draft watershed management plan included with the initial RFP to identify areas of concurrence and dissensus.

Three student proposals related to stormwater runoff mitigation and campus watershed resilience were also analyzed to identify frequently suggested stormwater BMPs and watershed management strategies (Table 2). The results were recorded alongside results from the professional proposals for a comprehensive review of all proposals to UR.

To inform this analysis, the typical volume of stormwater runoff from the UR campus during a 1-year 24-hour rain event was calculated using the Simple Method (Schueler, 1987 as cited in NCDENR, 2009). The Simple Method uses watershed drainage area, impervious area, and design storm depth to estimate stormwater runoff with minimal information (NCDENR, 2009).

First, the runoff coefficient for the campus watershed in 2014 was calculated using the observed relationship between per cent imperviousness and the runoff coefficient for several different watersheds:

$$RV = 0.05 + 0.9 \times IA$$

Where: 
RV = Runoff coefficient [storm runoff (in)/storm rainfall (in)]  
IA = Impervious fraction [impervious portion of drainage area (ac)/drainage area (ac)]

Second, the runoff coefficient was used to determine the volume of runoff from the campus watershed using the equation below:

$$V = 3630 \times RV \times RD \times A$$

Where: 
V = Volume of runoff from design storm (ft³)  
RD = Design storm rainfall depth (in)  
A = watershed area (ac)

The two calculations above were then repeated using a pre-development scenario for the campus in which the impervious fraction was zero (0). The estimated pre-development volume of stormwater runoff was then subtracted from the post-development (2014) volume to determine the volume of stormwater that needs to be controlled to return stormwater runoff from the UR campus watershed to predevelopment values.
Then, stormwater BMPs with sufficient datasets to produce summary statistics of study-based relative stormwater volume reduction were evaluated based on their ability to reduce concentrations of total suspended solids (TSS), total phosphorus and total nitrogen in stormwater runoff. These BMPs include grass strips, grass swales (bioswales), bioretention (with underdrains) and grass-lined surface detention basins. To calculate the per cent reduction in TSS, phosphorus and nitrogen, the following formula was used:

\[
\% \text{ reduction} = \frac{\text{In} - \text{Out}}{\text{In}} 
\]

Where: \( R_p = \) Percent reduction of a given pollutant, \( p \)

\( \text{In} = \) median influent concentration of pollutant \( p \) (mg/L)

\( \text{Out} = \) median effluent concentration of pollutant \( p \)

The four BMPs were then ranked based on their ability to reduce stormwater volume and pollution concentrations by scaling their relative reduction values from 0 - 1. For a given water quality or quantity parameter, the BMPs were scaled according to the following formula:

\[
\frac{\text{Normalized score}}{4} = \frac{\text{In} - \text{Out}}{\text{In}} - \frac{\text{Out}}{\text{In}} 
\]

For each of the BMPs, the normalized scores of its ability to reduce stormwater volume and concentrations of TSS, total nitrogen and total phosphorus were added together to produce an overall relative effectiveness score out of a possible 4 points.

3. Results

Of UR’s 30 peer institutions, six are located within the Chesapeake Bay watershed: Bucknell University, Colgate University, College of William and Mary, Dickinson College, Franklin & Marshall College, and Washington & Lee University. Of these six peer institutions all employed some kind of green LID for stormwater management but only two – College of William & Mary and Dickinson College – have formal, published stormwater management plans (Table 3). None of the six institutions had published watershed management plans.

A review of seven professional and student proposals for improved campus watershed management frequently identified the Westhampton Lake as a key area for water quality management on campus. Shoreline stabilization and repair of the buffer zone around the Westhampton Lake was the most common suggestion across all of the proposals analysed with six of seven proposals listing it as a proposed strategy (Table 4). Five of the seven proposals
suggested rainwater harvesting and reuse (Table 4). Other commonly proposed strategies included retrofitting impervious ground cover with permeable pavement and converting unnecessary turf to native vegetation cover which were both suggested in three proposals. Less common suggestions were bioswales, bioretention and floating wetlands with only two mentions each (Table 4).

The seven proposals also showed a strong affinity toward community outreach and education with four of the seven proposals including community outreach as a key element of the design process (Table 4). Student involvement – whether in monitoring, design, or place-based education– was also mentioned in four proposals: two student and two professional. It should be noted that one of the two professional proposals only listed student involvement as an optional component of the consultation process (Table 4).

Given an impervious fraction of 0.34, the runoff coefficient for the UR campus was calculated to be 0.3554. Based on point precipitation frequency estimates that a 1-year 24-hour storm event produced 2.74 inches of rain (Office of Water Prediction, 2017), stormwater runoff from a typical 24-hour rain event over UR’s 2014 campus was calculated to be 1,108,723.10 ft³. This is a notable difference from pre-development runoff which was estimated to be 155,994.81 ft³. Simple Method calculations, therefore, indicate that campus stormwater runoff has increased by 952,728.30 ft³ due to campus development.

Performance statistics for the four BMPs in question revealed that bioretention units with underdrains produced greater runoff volume reductions than grass strips, bioswales, and surface detention basins (Table 5). Reducing relative stormwater volume by 33%, surface detention basins were the least effective of the four BMPs in this category. Additionally, bioretention reduced TSS by approximately 75%, outperforming grass strips (57%), grass swales (16%) and detention basins (64%). Detention basins did, however, achieve the greatest reductions in phosphorus concentration (17%) with all other BMPs causing increases in total phosphorus concentration. Increases in total phosphorus concentration were evidenced by negative per cent reductions in phosphorus for grass strips (-21%), grass swales (-67%) and bioretention (-85%). Similarly, grass strips were the best of the four BMPs tested at nitrogen reduction, reducing total nitrogen concentrations by 19% while bioswales and detention basins produced increases in nitrogen concentration. The complete results from the analysis of performance statistics for the four BMPs are summarized in Table 5.

After scaling and ranking, results revealed that bioretention with underdrains was the top performer in runoff volume reduction and removal of total suspended solids (Table 6). Detention basins were relatively the most effective at reducing phosphorus concentrations while grass strips were better at reducing nitrogen concentrations. With a total of 2.91 of a possible 4 points, bioretention was relatively the most effective of the four BMPs at mitigating the effects of
stormwater runoff (Table 6). Grass strips were a close second (2.35) followed by detention basins (2.09) and bioswales (0.55).

4. Discussion & Conclusions

Results from a comparison of UR to its peer institutions indicated that with minimal use of green LID (bioswales) and no stormwater or watershed management plan, UR’s policies were on par with the majority of its peer institutions (Table 3). Given that only two of UR’s six peer institutions in the Chesapeake Bay watershed have a formal stormwater management plan (and none of the institutions has watershed management plans), the implementation of a comprehensive watershed management plan would place UR at the forefront of water-related issues in the region.

Strengthening UR’s stormwater management policies over its peer institutions’ is a value-add because it may increase the amount of students who choose to either apply to or attend the university (The Princeton Review 2019). In the age of climate change, potential university students are more environmentally conscious than ever before. Since 2008, when The Princeton Review (2019) first started surveying students on how colleges’ stances on environmental issues affected their decision to apply, student responses have always indicated a preference towards greener colleges.

Although all of UR’s peer institutions are not among its top admissions competitors, peer institutions were used for this comparison because the list had already been adjusted to account for resources. Lack of funding, data access and training are among some of the main factors affecting the effectiveness of universities at addressing sustainability issues and were controlled for using peer institutions (Velazquez et al. 2005).

The implementation of improved stormwater management practices would, however, place UR in line with its top admissions competitor, University of Virginia (UVA), which has already undergone an analysis of its watershed management strategies on its West Side campus (Judith Nitsch Engineering Inc, 2002). When creating a stormwater management model for UVA, contractors produced three hydrological models in order to determine best practices: one of campus area pre-development, another post-development, and a third of the area post-development with LID (Judith Nitsch Engineering, Inc., 2002). This practice is in keeping with current literature which suggests that the primary goal of LID is to replicate pre-development flow regimes in urban areas (Damodaram et al., 2010; Reichold et al., 2010).

Stormwater runoff from UR campus was calculated for a typical 24-hour rainstorm, using The Simple Method, to have increased by over 950,000 ft³ from pre-development volumes. This
suggests that in order to replicate pre-development flow regimes, LID would need to reduce UR’s stormwater volumes by at least 86%. Estimations of impervious land cover on campus were based on UR’s land use in 2014; since then impervious ground cover has increased with the completion of the Queally Center, new tennis courts and expansion of the Weinstein Recreation & Wellness Center. Therefore, stormwater runoff is likely to be higher than the calculations suggests.

Furthermore, while the Simple Method provides reasonable estimates of stormwater runoff, it is a gross oversimplification of the various interactions that control a hydrologic flow regime. The method is based solely on the observed relationship between stormwater runoff, impervious ground cover and the runoff coefficient (NCDENR, 2009). In actuality, hydrologic flow is also governed by soil type, evapotranspiration rates, slope and many other environmental conditions. For a more exact estimate, a more complex hydrologic model may be used.

Results from the review of proposals and BMP performance statistics suggest that green stormwater interventions could add value to the UR campus landscape. Proposals suggest major problems with TSS, nitrogen and phosphorus concentrations on campus which can be alleviated with green LID. The identification of these three pollutants as key issues for the UR campus watershed is consistent with water quality studies conducted on LWC and the Westhampton Lake (as cited in Holden 2015).

All four BMPs evaluated for their relative effectiveness at mitigating UR’s principal stormwater concerns were shown to be effective at reducing stormwater volume and TSS concentrations. However, grass strips, bioswales, and bioretention facilities were all seen to be net exporters of phosphorus (Table 5). Bioswales and detention basins were also net exporters of nitrogen (Table 5). The International Stormwater BMP Database (2016) suggests that the net export of nutrients from these BMPs may be linked to the media mixes, fertilization practices and erosion controls used during design, construction and maintenance. These interventions make use of soils which may release nutrients if the concentration of nutrients in the soil is higher than in the water. For the same reason, Dietz & Clausen (2005; 2006) suggest that for bioretention facilities, the elimination of the underdrain may increase overall pollution retention.

Based on the literature review and analysis conducted for this study, as well as the potential value-add to the campus community, the following strategies for addressing stormwater on UR’s campus are recommended:

1. **Shoreline Stabilization of the Westhampton Lake**

   With six of seven proposals highlighting the need to reduce erosion into the Westhampton Lake, the stabilization of the lake’s shoreline is a key area of opportunity
for improving water quality in the campus watershed. A vegetated buffer along the Richmond College, or northern, side of the Westhampton Lake would not only trap sediment before it enters the lake but also help stabilize the steep lake bank to reduce erosion (Holden, 2015; 3 North PLLC, 2012). As Holden (2015) notes, the Westhampton Forest acts as a natural vegetative buffer on the Westhampton College side of campus, eliminating the need for shoreline stabilization all around the lake. The Richmond College side of campus is also notably the side of campus with the greatest proportion of impervious ground cover (Fig. 3).

By reducing the amount of sediment into the Westhampton Lake, shoreline stabilization is likely to decrease the frequency with which the Westhampton lakes needs to be dredged and treated for nutrient pollution. Although sedimentation from water flowing into the Upper LWC is likely to continue, the proposed stabilization project would alleviate some of the maintenance costs for lake upkeep, adding value to the campus landscape.

A critical component of UR’s physical and cultural campus landscape, Westhampton Lake already holds great value for members of the campus community (Ahnell, Nuñez, & Rathlev, 2014). The prominence of the lake as both a central physical and cultural feature at UR suggests that a full shoreline stabilization project may be opposed by those who wish to preserve the current image of the lake. However, as a highly visible renovation, lake bank restoration would publicly demonstrate UR’s commitment to the environment and sustainability (Way, 2012). Additionally, the project is likely to garner student and community interest in environmental issues related to the Westhampton Lake and campus watershed, increasing the value of the campus landscape as a living lab and teaching tool (Way, 2012).

II. Rainwater harvesting

Rainwater cisterns capture and store water from the roofs of buildings for later use. Although never mentioned in UR’s draft watershed management plan, the majority of proposals suggested rainwater harvesting and reuse as a viable stormwater management strategy for the UR, likely because of its ease of implementation and relatively low costs compared to other green infrastructure projects (Table 4; 3 North PLLC, 2012; Greening Urban, 2012). A typical 5,000-gallon industrial rainwater cistern can range anywhere from $2,000 - $20,000 dollars (Greening Urban, 2012; RainHarvest Systems, 2019). Alderbashi, Collins & Wilkes (2014) have already identified Booker Hall as an ideal location for the launch of rainwater collection on campus; Holden (2015) and DePrete (2015 as cited in Holden, 2015) also recommend rainwater harvesting near the gym complex (i.e. Robins Stadium and Weinstein Center for Recreation and Wellness) to
mitigate large volumes of stormwater because of the high density of impervious surfaces in that area.

By reducing the volume of stormwater runoff in UR’s stormwater drainage system after a rain event, rainwater harvesting can greatly reduce runoff volume, erosion and pollution load. A certifiable BMP for stormwater credits from the DPU, rainwater harvesting can be applied towards UR’s stormwater fees, reducing campus utility costs (Richmond Department of Public Utilities, n.d.). Furthermore, if the collected stormwater is used by Facilities for irrigation, rainwater cisterns are likely to decrease campus potable water consumption and water utility bills as well (Alderbashi, Collins & Wilkes, 2014; Holden, 2014).

III. Installation of Permeable Pavement

The Simple Method identifies the proportion of impermeable ground cover as a primary driver of the runoff coefficient and stormwater runoff volume for a development. Pyke et al (2011) also suggest that stormwater runoff volume is most sensitive to changes in impervious site cover. By reducing the overall proportion of impervious ground cover on campus, UR can, therefore, notably reduce stormwater runoff volume from approximately 25% of its campus (Fig. 1).

A certifiable stormwater BMP with the Richmond DPU (n.d.), permeable pavement retrofits can also be applied as credits towards UR’s annual stormwater fees. Additionally, as stormwater fees are calculated based on impervious ground cover, the replacement of some impervious ground cover with permeable surfacing will likely decrease annual fees altogether.

IV. Bioretention (Rain Gardens)

Results indicated that bioretention facilities with underdrains are more effective at addressing UR’s primary water quality and quantity concerns than bioswales, the primary low-impact intervention used in UR’s stormwater infrastructure at the time of study (Table 5; Table 6; University of Richmond, 2019a). Of all the BMPs analyzed, bioretention facilities were among the top performers for all evaluation criteria except phosphorus reduction (Table 6). Despite the aforementioned shortcomings in phosphorus reduction, bioretention may still be an effective stormwater management strategy for UR. Because of their pollution-reducing properties, bioretention facilities qualify for credits from Richmond DPU (n.d.) for mitigating stormwater quality.
Bioretention basins with underdrains filter stormwater runoff through an engineered mix of soils to remove pollutants, before draining to an underground storm sewer system. The estimated 57% reduction in stormwater runoff volume occurs because some of the runoff that flows into the basin is absorbed by plantings, infiltrated into the soil below, or lost due to evapotranspiration (Table 5; Minnesota Pollution Control Agency, 2008).

As bioretention facilities, rain gardens with native plantings are a form of habitat creation for native creatures. Aesthetically pleasing and highly visible, rain gardens can be incorporated throughout campus, alongside buildings, and near parking lots to effectively manage stormwater runoff. Additionally, rain gardens are charismatic features which evoke reminders of nature in urban environments, increasing opportunities for environmental education on campus (Church, 2015).

UR has already exhibited willingness to install bioretention facilities on campus. The proposed watershed management plan issued with the initial RFP in 2011, included plans to construct bioretention systems in parking lots and along roadways as campus demonstration projects (University of Richmond, 2011).

While any of these recommendations may be effective at mitigating the effects of stormwater management, the efficacy and impact of intervention is greater if they are combined. For example, to return stormwater runoff volumes to pre-development levels using rainwater harvesting alone, UR would need at least 1,425 rainwater cisterns, holding approximately 5,000 gallons each.

Thus, the results support the initial hypothesis that a comprehensive watershed management plan that employs the use of green stormwater infrastructure for stormwater management is a value-add for UR. Charismatic, effective and attractive, the proposed recommendations for stormwater management offer UR long-term savings on their stormwater fees, a competitive edge among peer institutions, and increased environmental education opportunities. The design, implementation and monitoring of these projects provide opportunities for student involvement and academic enrichment.
References


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Draper Aden Associates. (2012). UR - Westhampton/Little Westham Creek Stormwater Study [written proposal to the University of Richmond].


Green Urban. (2012). Watershed Proposal [written proposal to the University of Richmond].


3 North, PLLC. (2012). University of Richmond Watershed Management Plan [written proposal to the University of Richmond].
Figure 1. Pie chart illustrating the land cover distribution on the University of Richmond campus in 2014. Land cover estimates are based on land cover classification of UR’s campus according to an automated feature extraction rule set output from eCognition using the 2014 NAIP dataset. Note that 34% of the campus area is covered with impervious surfaces, which is mostly groundcover like roads, parking lots and walkways.
Figure 2. Map of the Little Westham Creek Watershed (top) and water flow lines through the wider watershed to Little Westham Creek and the James River (below) created by Holden (2014). The University of Richmond Campus is highlighted in red.
Figure 3. Map of the University of Richmond’s stormwater drainage system. Stormwater inlets are highlighted by red circles while red arrows denote areas where stormwater exits the systems. Stormwater travels throughout the drainage system through a system of underground pipes and conduits. Impervious ground cover is shown in grey. Note that most of the stormwater from the Richmond College (north) side of campus drains directly into the Westhampton Lake.

Table 1. Summary of responses to the Request for Proposals for consultation on a watershed management plan for The University of Richmond.

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<tr>
<td>SP003</td>
<td>Ahnell, Nunez &amp; Rathlev</td>
<td>2014</td>
<td>Clia</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2. Summary of student proposals utilized in this study. All proposals were chosen based on their focus on either stormwater runoff mitigation or improving the resiliency of the campus watershed.

<table>
<thead>
<tr>
<th>Code</th>
<th>Author(s)</th>
<th>Date</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>PP002</td>
<td>Draper Aden Associates</td>
<td>4 April 2012</td>
<td>UR - Westhampton/Little Westham Creek Stormwater Study</td>
</tr>
<tr>
<td>PP003</td>
<td>3 North, PLLC</td>
<td>30 March 2012</td>
<td>University of Richmond Watershed Management Plan</td>
</tr>
<tr>
<td>PP004</td>
<td>Greening Urban</td>
<td>5 April 2012</td>
<td>Watershed Proposal</td>
</tr>
</tbody>
</table>

Table 3. Results from the review of peer institutions' rainwater management policies. Assessments of whether or not institutions utilizes LID or had water management plans were made based on the institutions' most recent STARS™ reports and web searches for campus sustainability intitatives.
<table>
<thead>
<tr>
<th>Institution</th>
<th>Location</th>
<th>BMPs Suggested</th>
<th>Strategies Suggested</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bucknell University</td>
<td>West Branch Susquehanna</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Colgate University</td>
<td>Upper Susquehanna</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>College of William and Mary</td>
<td>James</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Dickinson College</td>
<td>Lower Susquehanna</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Franklin &amp; Marshall College</td>
<td>Lower Susquehanna</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Washington &amp; Lee</td>
<td>James</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>University of Richmond</td>
<td>James</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>

Table 4. Summary of BMPs and strategies suggested in stormwater/watershed management proposals to The University of Richmond.

<table>
<thead>
<tr>
<th>Code</th>
<th>Bioswales</th>
<th>Bioretention</th>
<th>Rainwater Harvesting/Resus</th>
<th>Buffers for Erosion Mitigation around the Westhampton Lake</th>
<th>Floating Wetlands</th>
<th>Impervious Cover Removal/Pavement Retrofit</th>
<th>Landscape Conversions from Turf to Natural Vegetation</th>
<th>Community Outreach</th>
<th>Student Involvement (Monitoring/Place-based Education)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PP001</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X (outdoor learning spaces; optional workshop to get student &amp; community input)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PP002</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PP003</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>PP004</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SP001</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
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<td>X</td>
<td></td>
<td>X</td>
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<tr>
<td>SP002</td>
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<td>X</td>
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</tr>
</tbody>
</table>
Table 5. Summary of performance statistics for BMPs statistically shown to reduce stormwater runoff volume. Percentage values represent the relative ability of each of the BMPs listed to reduce stormwater runoff volume and concentrations of total suspended solids (TSS), total phosphorus and total nitrogen. Percentage values for TSS, phosphorus and nitrogen reduction were calculated using the median influent and effluent concentrations of each pollutant, respectively.

<table>
<thead>
<tr>
<th>BMP Category</th>
<th>Median Runoff Reduction (%)</th>
<th>TSS Reduction (%)</th>
<th>Phosphorus Reduction (%)</th>
<th>Nitrogen Reduction (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biofilter - Grass Strips</td>
<td>34%</td>
<td>57%</td>
<td>-21%</td>
<td>19%</td>
</tr>
<tr>
<td>Biofilter - Grass Swales</td>
<td>42%</td>
<td>16%</td>
<td>-67%</td>
<td>-12%</td>
</tr>
<tr>
<td>Bioretention (with underdrains)</td>
<td>57%</td>
<td>75%</td>
<td>-85%</td>
<td>16%</td>
</tr>
<tr>
<td>Detention Basins - Surface, Grass Lines</td>
<td>33%</td>
<td>64%</td>
<td>17%</td>
<td>-3%</td>
</tr>
</tbody>
</table>

Table 6. Normalized results from the performance evaluation of possible BMPs for the University of Richmond campus. Values for each of the evaluation criteria were scaled from 0 -1 with 1 representing the BMP category with the best performance in that criterion. The relative effectiveness score is the sum of all the evaluation criteria.

<table>
<thead>
<tr>
<th>BMP Category</th>
<th>Runoff Volume Reduction</th>
<th>TSS Reduction</th>
<th>Phosphorus Reduction</th>
<th>Nitrogen Reduction</th>
<th>Relative Effectiveness Score (out of 4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biofilter - Grass Strips</td>
<td>0.04</td>
<td>0.69</td>
<td>0.62</td>
<td>1.00</td>
<td>2.35</td>
</tr>
<tr>
<td>Biofilter - Grass Swales</td>
<td>0.38</td>
<td>0.00</td>
<td>0.18</td>
<td>0.00</td>
<td>0.55</td>
</tr>
<tr>
<td>Bioretention</td>
<td>1.00</td>
<td>1.01</td>
<td></td>
<td>0.90</td>
<td>2.91</td>
</tr>
<tr>
<td>Detention Basins - Surface, Grass Lines</td>
<td></td>
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<td></td>
<td></td>
<td></td>
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<td>----------------------------------------</td>
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</tr>
<tr>
<td></td>
<td>0.00</td>
<td>0.82</td>
<td>1.00</td>
<td>0.27</td>
<td>2.09</td>
</tr>
</tbody>
</table>