Sustainable Stormwater Management as an Opportunity for Campus and Community-based Engineering Education

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Abstract

Sustainable stormwater best management practices (BMPs) seek to mimic natural or predevelopment site hydrology, improve runoff quality, can provide small islands of green space in urban environments, and capture a resource that is otherwise unused. Because existing urban areas, including college and university campuses, were largely developed prior to the implementation of ordinances requiring BMPs, an opportunity arises for incorporating both on-campus and community stormwater retrofit projects into civil and environmental engineering courses, and in the process, exploring sustainability in a quantifiable way that tangibly connects to the student experience. This paper will describe a case study of a five-year project in which students conceptualized, designed, helped to construct, and now monitor a stormwater detention wetland near campus. The objective of the project was three-fold: (1) to address an existing runoff problem that was degrading a high-quality stream in the local community, (2) to involve undergraduate students in an integral way in the design process, system maintenance, and in performance monitoring, and (3) to use the project as a practical illustration of how sustainability constraints are incorporated into water resources engineering. The importance of ongoing partnerships with the local municipality, regulatory agencies, and watershed advocacy organizations is emphasized as key to sustaining multiple-year off-campus projects. Qualitative assessment suggests the project was highly motivational to many students; however, a drawback is that a given class of students only experiences a portion of the overall project.

Introduction

Motivating undergraduate students through project-based and community-based approaches is not a new idea, and is becoming more and more prevalent in engineering programs in the U.S. and worldwide[1-6]. The growth of programs such as Purdue's Engineering Projects in Community Service (EPICs)[7] and Engineers Without Borders (EWB)[8], which also includes sustainability as a central theme, is testament to the success of these approaches. However, the execution and assessment of real-world design projects within the academic constraints and framework remains a substantial challenge[9]. The reality is that incorporating such projects into the classroom invariably involves trade-offs, for example, between the educational value of a real-world real-time project vs. that of a simulated project that might better replicate the entire design process for a particular class of students. Real projects in civil and environmental engineering involve a series of stages (through conception, analysis, design, funding, bidding, construction, and post-construction assessment) whose duration is typically several years, certainly longer than a single semester or academic year. Yet there is an undeniable motivational aspect to a real community-based project that simply cannot be replicated with a simulated design exercise. A particular challenge for the instructor using a project-based approach is to structure the project so that the students involved in a particular component are also able to grasp the overall context and meaningfully apply their analysis and design skills, despite directly experiencing only a subset of the steps in the design and construction process.

This paper first makes a case for sustainable stormwater best management practice retrofits as an opportunity for community and campus-based engineering education, and then describes a case study at Lafayette College in which civil and environmental engineering students in a variety of classes over five years conceptualized, designed, helped to construct, and now monitor a stormwater detention wetland adjacent to campus. The objective of the project was three-fold: (1) to address an existing runoff problem that was degrading a high-quality stream in the local community, (2) to involve undergraduate students in an integral way in the design process, system maintenance, and in performance monitoring, and (3) to use the project as a practical illustration of how sustainability constraints are incorporated into water resources engineering practice. As the project evolved without a structured assessment process in place, the educational impact to students was assessed qualitatively through informal interviews and surveys.

Background

Sustainability in hydrologic engineering

Consideration of sustainability has become integral to the civil and environmental engineering disciplines[10], and sustainability outcomes are part of both the civil engineering and the environmental engineering body of knowledge (BOK) documents. Furthermore, adherence to the "principles of sustainable development" is encouraged in both the ASCE and NSPE codes of ethics. In the field of hydrologic engineering, this entails consideration of impacts of development projects on all aspects of the water cycle and the ecosystems that depend on it, as well as the needs of various human stake-holders. For stormwater management in particular, the subject of this paper, a guiding tenet is that sustainability implies striving to maintain the "natural" or predevelopment water balance and water quality, from the river basin scale down to the individual site or campus scale. How one actually defines and attains a "natural" water balance is a complex subject[11] and is well beyond the scope of this paper. However, this is a particularly useful application of the concept of sustainability for engineering students, because rather than an abstract ideal, it can be connected to a specific, bounded, quantifiable local issue – *How does our campus and/or community affect local hydrology and water quality*? What students will invariably find is that a college campus with conventional stormwater controls has a very different water balance, runoff behavior, and water quality impact than it would under a more natural vegetated state. To understand this statement we need to take a quick tour of the history of stormwater management.

Evolution of stormwater management

For decades, the state-of-the-art in stormwater control was to engineer conveyance systems to move water quickly and efficiently off-site to the nearest water body. With the growing recognition of the impact of land development on downstream flooding in the 1960s and 70s, detention basins began to be used to reduce the peak runoff flows from large storm events. Some areas later developed watershed-based stormwater management plans, which were implemented into state and/or local land development ordinances. Beginning in the 1990s, with the understanding that conventional detention-based stormwater management approaches did not adequately address many of the impacts of land development on streams and with new federal requirements for urban runoff quality, states began implementing new stormwater controls that emphasized reduction of runoff and treatment at its source through infiltration, bioretention, and other best management practices ("stormwater BMPs"). Cities such as Philadelphia and New York are increasingly looking to "green infrastructure" (such as green roofs, rain gardens, and other vegetation-based BMPs) to comply with EPA urban runoff discharge standards regarding combined sewer overflows. Both cities have embarked on ambitious plans to incorporate a variety of BMPs to reduce loading of urban runoff to the sewer systems, in part because the alternative "gray infrastructure" retrofits (constructing new separate storm drains and underground detention) are prohibitively expensive. A 'Green Infrastructure for Clean Water Act of 2010' bill (S. 3561) was introduced into the U.S. Senate in summer 2010 to provide incentives for more communities to adopt such practices. Based on these developments it is evident that 21st century stormwater management involves a more holistic, ecological-based approach to design than civil engineering students have learned in previous decades. This approach integrates traditional civil engineering with environmental science and engineering, landscape architecture, and ecology, making it an exciting challenge for civil & environmental engineering academics and professionals.

An opportunity for campus-based sustainable stormwater retrofits

Because the majority of college and university campus construction predates current stormwater management practices based on BMPs and green infrastructure, it is clear that most campuses are not state-of-the-art nor sustainable with respect to stormwater runoff and impacts on local streams and water bodies. However, many colleges and universities have signed onto the American College & University Presidents Climate Commitment, which commits them to take concrete steps to reduce greenhouse gas emissions. Although focused on "climate neutrality", the agreement also includes the idea of integrating sustainability into the curriculum, and has helped to promote a wider conversation about the college and university role in modeling sustainable development. In my own experience teaching an introductory (sophomore-level) course in environmental engineering, it is increasingly evident that many civil and environmental engineering students already have a keen interest in sustainability, renewable energy, and green design. Thus the opportunity to do something tangible with regard to campus or community sustainability is highly motivating to these students. Although there is no legal requirement to retrofit existing urban development to new standards, there is a ready opportunity for campus or community-based curricular projects in which students design (and perhaps build) sustainable stormwater retrofits. This is similar to the way in which campus construction projects can serve as a laboratory for students learning construction management[12]. Retrofits can later be instrumented and monitored after installation, providing an opportunity for campus-based research[13]. The remainder of this paper describes how such a project was implemented at a site near Lafayette College.

Case Study

In September 2004, the remains of Hurricane Ivan moved north through the mid-Atlantic region, resulting in widespread localized flooding. In eastern Pennsylvania, Ivan caused major damage to many small tributaries whose headwaters had become suburbanized over the previous 30 years. Severe damage to streets and sidewalks occurred below an eroding stormwater channel (see Figure 1) that eventually discharges to Bushkill Creek, designated a "high quality cold water fishery", adjacent to Lafayette College. Bushkill Creek forms the western and southern boundaries of campus, and several faculty members in Civil & Environmental Engineering, Biology, and Geology & Environmental Geosciences have done extensive collaborative research with students in its watershed, as well as using it for an outside laboratory[14, 15].

Figure 1. Damage caused by remnants of Hurricane Ivan, September 2004, near Lafayette College, Easton, PA

Through conversations with the local stream conservancy, the municipality, and a state representative interested in developing a solution to the problem, we decided to have undergraduate students investigate possible retrofits at the site. At the time (spring 2005) I taught a portion of the junior level design course (CE 372) that was divided into four 3-4 week modules, corresponding to four distinct areas within civil & environmental engineering. While the project could have been developed into a capstone design, I developed a more limited scope for the junior-level class, consisting of initial field work and analysis to quantify the problem, and come up with a design concept. Their tasks included topographic surveying, modeling of flow rates into the channel from the upstream watershed, and estimation of the amount of storage volume needed to reduce the peak flows by 50%. The possibility of installing a state-of-the-art detention facility in a local municipal park to reduce the flows through the stormwater channel was first proposed at the end of the spring 2005 semester. The park is shown in Figure 2 – note the cattails (an obligate wetland plant) at the back of the field, indicating the potential for a detention wetland with a permanent water source. In part because of the wet area that limited use of the field for sports, the park had suffered from years of neglect and the municipality was interested in investing some resources to improve its connection to the surrounding community.

Figure 2. Students studying subsurface conditions near an existing low-quality wetland at the rear of the park, and installing a V-notch weir to measure baseflow in spring 2006

Another group in the junior design class returned the following spring (2006) with a different objective, to develop a conceptual design for a stormwater detention wetland in the park. Tasks included measurements of baseflow rates, soil borings to determine depth of saturation and bedrock, sizing of the basin and an outflow structure, and routing of peak flows through the facility. A competitive aspect was introduced wherein the top two reports would be submitted to the municipality and watershed organization to serve as the basis for a grant proposal. The students' work demonstrated that about 1/3 of the open area of the park would have to be converted to a detention wetland if the project was to meet the design goals of 50% reduction in peak flows – based on input from the municipality and several community meetings this was deemed feasible (although not all community members were in favor of the project).

We then teamed with the county conservation district Watershed Specialist and the municipal government to submit a proposal for state funding (through the PADEP Growing Greener program) to develop final design drawings and bid documents based on the preliminary detention design concept developed by the students. After a long wait, the proposal was successful. Using a bid process coordinated by the municipality with participation by the author (DB) and the Watershed Specialist, a consultant was selected to develop the final design. After the design documents were received, a second grant proposal was submitted to the state for construction funding. This grant was also successful and the project was put out to bid in 2008-09.

The project was constructed beginning in 2009 with completion in spring 2010. During this time the fall 2009 hydrology class (CE 421), which is entirely project-based, observed the construction and developed a detailed stormwater wetland monitoring plan based on a literature review and EPA guidance documents. In order for them to experience and understand the design phase of the wetland that was now under construction, I had also tasked them with a separate detention basin retrofit project in which they took a conventional mowed detention basin near the Lafayette athletic fields and converted it to an extended naturalized design with a new outlet structure. For this retrofit project we had access to the original wetland design consultant for feedback and critique.

As shown in Figure 3, the completed site includes a stormwater diversion to take flow away from the eroding channel into the constructed wetland, and some aesthetic enhancements such as a split-rail fence and fountain. The municipality also installed new playground equipment and basketball court at the park. In spring 2010, the water resources engineering class (CE 351) worked with stream conservancy volunteers to plant the wetland with native shrubs and perennials adapted to periodic inundation. This is the required course that includes objectives related to sustainability, and low-impact stormwater management with green infrastructure (such as the wetland) is used as a specific example of sustainable development. During summer 2010, a summer research student installed a down-well pressure transducer in 2-inch PVC tube to continuously monitor stage and outflow from the wetland (see Figure 4). Finally, the quarterly water quality monitoring program designed in fall 2009 was put in place in fall 2010 by students in hydrology (CE 421).

In part because the project was off-campus, it required the sustained effort of a number of partners to see it through from its beginning stages to construction. Particularly in the regulatory aspects (wetlands and erosion/sedimentation permitting issues) it was invaluable to have the county conservation district involved in the project. The construction phase required a partner (the local municipality) capable of running the bid process and responsible for project management; however, for an on-campus project this would be handled through the campus facilities or buildings department. Despite the substantial logistical effort involved, the project has provided many opportunities for students to contribute their ideas to the conceptualization, design, and monitoring of a constructed stormwater wetland. Students learned the importance of building community relationships and applied the concepts of sustainable design. In a recent visit to the site to close out the state grant, the PADEP project officer stated that the project was one of the top five Growing Greener-funded projects he had seen.


Figure 3. Construction of the stormwater diversion channel in fall 2009; wetland planting by students in spring 2010

Figure 4. Installation of continuous flow monitoring system in summer, and water quality monitoring in fall 2010

Assessment

A total of approximately 100 civil & environmental engineering students contributed to varying degrees to the design, construction, and monitoring of the project between 2005 and 2010 (see Table 1). In addition, two students have worked on automated data acquisition and analysis as an independent research project on the hydraulics of concrete outlet structures.

Table 1. Courses involved with the stormwater detention wetland project

Year	Course	Description	Students
2005	CE 372	Jr Design w/ lab	25
2006	CE 372	Jr Design w/ lab	25
2009	CE 421	Hydrology	12
2010	CE 351	Water Resources w/ lab	30
2010	CE 421	Hydrology	15

In addition to the written reports submitted by the students, surveys were used to assess effectiveness – some responses are listed below, illustrating both positive and negative aspects of the project:

> "I feel that it was a great project for a senior level class because it effectively bridged the gap between coming out of a strictly academic setting and transitioning into the work world where you would find yourself working on these types of design projects"

> "The fact that there was a local problem that college students could help to solve really acted to motivate me because I knew I was working on something that could make a difference in the community"

> "It was by far the most enjoyable of the design units that semester. I attribute that to the real-world application and balance between field and theoretical work. This project gave me my first taste of the sort of stream & wetland restoration work that I would eventually pursue in my career"

> "I also enjoyed the teamwork approach that was used to attack the project. Not only did we work in our groups of four but the whole class worked together to develop the base plan, drainage maps, and perform various field tests"

> "While I was only involved in the final stages of planting and weeding, it was really rewarding to be helping the community with something that I actually had no idea existed"

> Overall I thought the project was a great concept because it involved multiple aspects of civil engineering; drainage design, hydrology, geotechnical, and surveying. It was a great project to prepare students for an actual engineering project from start to finish

> "It almost felt like more of a restoration project [than design] in the way that it would incorporate local plants and educational elements"

> "With the compressed time frame, there wasn't much of a chance to review a teammate's work and try out different ideas …It was a bit overwhelming to be tasked with an entire preliminary design"

> "Ultimately, it was up to the design groups to weigh the importance of competing factors, and make a recommendation based on the client's goals and objectives (city of Easton, etc.). The competing objectives were frustrating but realistic, and, as a student in engineering, learning to manage these may have trumped the value of technical knowledge"

Comments such as these suggest that on-campus or community-based stormwater retrofit projects have considerable potential for motivating undergraduate students interested in water resources and environmental engineering and sustainability. However they also illustrate that faculty must find creative ways to structure projects so that students can do meaningful design work within curricular time constraints. Probably the greatest obstacle to implementing such projects is lack of funding, given that there is no legal requirement to retrofit existing urban development to new stormwater ordinance standards. However, as college campuses are constantly infilling and remodeling existing buildings and spaces, opportunities will periodically arise for faculty and students to contribute to sustainable stormwater design on-campus. Furthermore, it is my experience that community watershed organizations are typically thrilled to partner with undergraduate students in furthering their goals for watershed restoration and protection. In addition to stormwater wetlands as discussed here, detention basin retrofit/naturalization is a good example of the kind of design project that can benefit both engineering students and watershed advocacy groups. At Lafayette, current seniors (class of 2011) have developed a "sustainable stormwater management plan" for the college that quantifies the current water budget and highlights priority retrofit projects on our campus.

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