Expanding the Presence of Stormwater Management in Undergraduate Civil Engineering

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Introduction

Stormwater management is a rapidly changing field, becoming increasingly complex as the National Pollutant Discharge Elimination System (NPDES) expands to include more stringent requirements and smaller cities[1]. Recently the Environmental Protection Agency (EPA) declared unmanaged stormwater the most significant threat to surface water bodies[2] and estimates an investment of $188 billion is necessary to manage stormwater and preserve the quality of our nation's waters[3]. Considering an investment of this size could create 1.9 million jobs, the anticipated demand for engineers with stormwater management skills is high. However, few undergraduate programs offer classes focused on stormwater management. Instead, most undergraduate programs place the foundation and theory for stormwater management application in traditional Civil Engineering courses such as water resources, hydrology, open channel flow, and environmental engineering. To provide engineering graduates with both a solid foundation in engineering analysis as well as a practical application of that knowledge, it is desirable to create a pathway for students to develop stormwater engineering skills by participating in real projects.

A promising approach provides students a significant project experience through a partnership between engineering educators, students, and a municipality regulated under an NPDES stormwater permit. In particular, many permittees are required to monitor the effectiveness of structural best management practices (BMPs) to meet water quality and quantity requirements. Since the majority of stormwater funding is from municipalities, many face financial constraints. Students assisting with required monitoring could mutually benefit all partners by providing experiential learning experiences and reducing permit compliance cost when supporting this type of cooperative project. This paper describes a multi-year project developed in partnership between Gonzaga University and a municipality with the goal of expanding opportunities for students to develop stormwater engineering skills within the current university curriculum. The project starts as a capstone design courses where students design a BMP and a BMP monitoring system as well as prepare technical documentation consistent with the EPA requirements for stormwater management projects across the country. Future efforts will construct the BMP equipped with a monitoring system, establish a monitoring program, and integrate monitoring activities into existing related civil engineering courses.

This paper presents a case study focused on the first year of the cooperative stormwater project, which provides the basis for assessing the potential benefits of the project to the university, the municipality, and the students. Assessment of the case study focuses on the applicability of the project to meet required learning outcomes as well as survey responses from students and the municipality. Plans for integrating the BMP monitoring into other university course are also considered based on related studies as well as survey responses from stormwater practitioners. This paper addresses the following research questions:

1. How can the capstone design course objectives simultaneously meet ABET requirements while also providing students with an increased opportunity to gain experience and skills common to stormwater practitioners?

2. How can a partnership between a university and municipality best support educational outcomes and meet NPDES permit requirements?
3. How might integration of BMP monitoring support the objectives for other civil engineering courses and expand student's stormwater learning opportunities?
4. What do municipalities need from capstone projects to make the project valuable to them? The value perceived would act as incentive to support this type of future projects.

Background

Development of Stormwater Management Policy

Managing stormwater discharges in the United States began in the 1800's when industrial development resulted in the urbanization of cities as settlers relocated in search of economic opportunities. Since then, stormwater management has evolved based on the needs of the growing population as well as increasingly stringent environmental regulations[1]. A large paradigm shift occurred in 1987 when an amendment to the Clean Water Act expanded the NPDES permit program to include stormwater discharges[4]. The goal of the amendment was to reduce the impact of urban stormwater runoff on receiving water bodies. Based on the 1987 law, owners of municipal separate storm sewer systems (MS4) were issued NPDES stormwater permit permits in two phases[5].

An NPDES permit requires permittees to the development a stormwater management plan, which defines how the permittees will comply with six minimum control measures, listed in Table 1 with the goal of protecting receiving water bodies and reducing polluted discharges[6]. Some stormwater plans generally include guidance for selecting, designing, and maintaining BMPs. Where a BMP is a structural or managerial practices used to meet NPDES requirements by reducing stormwater pollutant loads and volumes[7-8]. BMP design guidance reflects generally accepted engineering practices and is customization for the specific regional conditions including; pollutant concerns, terrain, hydrology, issues with receiving waters, and site conditions[9-10]. The addition of a new or the modification of an existing BMP requires a study to demonstrate the effectiveness of the proposed BMP for meeting NPDES permit requirements. Such a study involves developing a quality assurance project plan (QAPP), that is approved by the EPA and generally describes the study objectives along with the procedures necessary to achieve those objectives[11].

While the passage of the Clean Water Act and the implementation of NPDES permits, has improved the quality of national water bodies, recent studies indicate that over half the water bodies remain in poor condition with untreated urban runoff identified as a significant source of the pollutants[2-12]. In response to these studies, EPA intends to reduce adverse impacts to receiving water bodies by implementing more stringent stormwater requirements and expanding NPDES permit coverage to include more locations[13]. Considering current NPDES stormwater permits only cover about 2% of the nation's land areas[5] as well as the proposed changes, it is anticipated that there will be a high demand for qualified engineering professionals capable of completing stormwater management projects, especially Civil Engineers who typically serve as the lead for these projects[14].

Table 1. Six Minimum Control Measures

Minimum Control Measures	Objective
Public Education & Outreach	Informing citizens about the impacts of polluted stormwater runoff discharges on water quality
Public Participation	Providing opportunities for citizens to participate in program development and implementation
Illicit Discharge Detection and Elimination (IDDE)	Developing an implementation program to detect and eliminate illicit storm sewer systems discharges
Construction Site Runoff Control	Developing, implementing, and enforcing a construction erosion and sediment control program
Post Construction - for New & Re-developed Sites ≥ 1 Acre	Developing, implementing, and enforcing a post construction program to address discharges including; use of BMPs
Pollution Prevention/Good Housekeeping	Developing and implementing a program to prevent/reduce pollutant runoff including training staff

University-Industry Collaborations and the Status of Civil Engineering Curriculum

A 2001 national survey of civil engineering curriculum noted that because of the "increased specialization in the practice of civil engineering", it is no longer possible for undergraduate students to graduate with "a well-rounded fundamental education in all aspects of civil engineering"[15]. Instead, recommendations for undergraduate civil engineering education include preparing students to become lifelong learners, integrating curricular topics in a meaningful way, and providing students with the practical application and experience of theoretical concepts[15-19]. Approaches universities have used to address these recommendation include project based courses, cooperative education, and university-industry collaborations[15,19-22].

Stormwater university-industry collaborations have the potential to combine these approaches with many developed as either project-based or community-based projects where students focus on the design, maintenance and/or monitoring of BMPs. Most appear to align with university learning objectives and the projects are frequently integrated into multiple civil engineering courses including; water resources, hydrology, design, open channel flow, and environmental engineering[23-26]. Of the studies reviewed, only a few attempted to also align learning objectives with the six minimum control measures objectives seen in Table 1 and none were found that included having students prepare technical documentation consistent with the EPA requirements for stormwater management projects across the country. Considering that collaborations are found to be most effective when they add value to all parties[20], expanding the scope of stormwater collaborative project to align with permit requirements could offer an effective means to expand stormwater educational opportunities in undergraduate programs and assist practitioners in meeting NPDES permit requirements.

Project Overview

Bio-infiltration ponds are a widely used regional stormwater BMP with approximately twenty of these ponds located around Gonzaga University's campus. Characterized as a shallow vegetated depression, these BMPs are typically located adjacent to a pollutant generating impervious surface, such as parking lots as shown in Figure 1. Bio-infiltration ponds combine plant material and soil to reduce stormwater pollutants using filtration, natural degradation and infiltration of the treated stormwater into the ground.

Figure 1. Existing Bio-infiltration Pond

Specific to this project, proposed changes to the 2018 NPDES permit include requirements for the infield monitoring of selected BMPs as well as an annual report summarizing the monitoring findings[27]. Currently the municipality achieves stormwater permit compliance through the presumptive approach meaning that if the BMP design follows EPA approved guidance, regulatory agencies presume the BMP will meet water quality and quantity. With proposed NPDES permit changes, the municipality will be required to demonstrate that selected BMPs meet permit requirements by collecting and evaluating infield BMP monitoring data. Monitoring the bio-infiltration pond BMP presents a challenge since treated stormwater infiltrates into the ground and there is no easily accessed surface outflow to measure or sample[28]. To complicate implementation of BMP monitoring programs, currently no guidelines exist for designing an effective monitoring system instead the available guidance focuses on procedures for collecting stormwater samples[10,29].

In preparation of future NPDES BMP monitoring requirements, a multi-year collaboration has been developed between Gonzaga University and Spokane County, a nearby Phase II NPDES municipality of 240,000 people. The goal of the project is to consider how practical stormwater experience could be integrated into Gonzaga's existing civil engineering curriculum while at the same time providing Spokane County with an opportunity to prepare for the 2018 NPDES permit changes by having students evaluate different BMP monitoring systems and the effectiveness of the BMP . The project started in the fall of 2013 as a civil engineering capstone design project with a team of students designing a multi-cell bio-infiltration pond equipped with a different monitoring systems. Year one activities are described in the case study section of this paper. During the summer of 2014, construction of the bio-infiltration pond BMP and monitoring systems will occur on Gonzaga's campus. Post construction plans for this project are described in the Future Plans and Considerations section of this paper.

Overview of the Gonzaga University Civil Engineering Capstone Design Course

The first two years of the multi-year project include integrating the BMP monitoring project into two different capstone design courses. At Gonzaga, this course is a two-semester sequence, which requires a team of student's to work with a faculty advisor and a liaison engineer who typically sponsors the project. The goal of the capstone course is to provide a "practical lab" type experience for students to develop an engineering design. Table 2 provides a summary of the specific capstone course goals, skill development, and learning outcomes.

Table 2. Summary of Capstone Design Goals, Skill Development, and Learning Outcomes

Capstone Course Goals	
1.	Developing an understanding of a real problem to allow a successful solution to be planned. Gathering information from technical or commercial literature.
2.	Writing technical documents for purposes of proposals, presentations, status reports and project reports.
3.	Planning and scheduling of engineering work using common project management tools.
4.	Completion of various engineering analysis and design development required to determine a feasible solution to a specific project.
5.	Evaluation of alternative approaches in achieving a project solution.
Capstone Student Skill Development	
1.	Open-ended design problem solutions.
2.	Working cooperatively in a team environment.
3.	Communicating effectively in technical documents using drawings, written, and spoken formats to a variety of audiences.
4.	Understanding the technical, economic, environmental, and managerial aspects of projects.
5.	Incorporating non-technical aspects of engineering decisions that address safety, ethics and professional responsibilities.
Capstone Learning Outcomes	
1.	Prepare a project proposal for submission to a potential project sponsor.
2.	Work in a team format to complete a variety of engineering tasks in an effort to meet scheduled project goals.
3.	Prepare and make a technical presentation addressing the status and goals of a realistic civil engineering project. Respond to questions posed by engineers about the project presented.
4.	Complete a variety of engineering tasks that are inherent in civil engineering practice in a project team.
5.	Collect required information, perform required analysis, and develop required work products to move a project toward a timely completion.
6.	Interact with a variety of project stakeholders appropriately. Interactions with team members, faculty advisor, suppliers, citizen groups, regulators, and sponsors are included. Productively communicate project activities to stakeholders.
7.	Collect required information, perform required analysis, and develop required work products to complete a realistic project.
8.	Prepare and make a comprehensive technical presentation addressing the completed design for a realistic civil engineering project. Respond to questions posed by engineers about the project presented

Case Study

The case study focuses on the first year of the project, which began in the fall of 2013 with a team of four civil engineering students. The students' goal was to design a multi-cell bio-infiltration pond BMP with different monitoring systems for each cell. Year one tasks included: a literature search of monitoring systems, selection of a suitable on campus site for constructing the BMP, a designing and developing plans sheets for the BMP and monitoring system, development of a final technical report in the form of a QAPP, preparation of a final project poster display, and production of a BMP monitoring system training manual for future students. The following section illustrates how the year one tasks aligned with the seven required project tasks for capstone design courses and specifically highlights how the practical stormwater experiences that support the NPDES permit were integrated into the class.

1) Project Management and Coordination - This included weekly project team meetings with the advisor as well as occasional meetings with the liaison engineer. In addition, since the final QAPP will require approval by the regulatory authority, some meetings also included the local NPDES stormwater permit coordinator. Activities required to support the meetings included developing meeting agendas and minutes, maintaining a project schedule, and developing the construction cost estimate.
2) Project Data Collection - The data collection for this project had three components: (1) a detailed literature search to understand the technical aspects of the BMP performance and to develop a basis for the monitoring system design, (2) collection of the pertinent NPDES permit requirements, related regulations, and design guidance from stormwater manuals, and (3) adequate collection of site data including soil samples and surveying.
3) Bio-Infiltration Pond BMP and BMP Monitoring System Design - The student team designed a multi-cell bio-infiltration pond along with a different BMP monitoring system for each cell. To accomplish this, the student team employed anticipated NPDES permit requirements for monitoring as well as current regional BMP design guidelines. The final pond designs include a flow splitter that will equally distributed flow to each cell. The multi-cell configuration is not typically part of the pond design; however, the students selected this design to allow for a side-by-side comparison of the different monitoring system. Students also developed a training manual for future students that describe the monitoring system operation and maintenance requirements. Stormwater training supports compliance for Spokane County with one of the six minimum control measures shown in Table 1, specifically Pollution Prevention/Good Housekeeping.
4) Select Site - Students were required to find an on campus site suitable for locating an infiltration BMP and supporting monitoring activities. This required students to become familiar with the site suitability requirements for locating infiltration BMPs. In addition, since no guidance existed for locating a BMP monitoring site, the students had to develop their own selection process for evaluating and prioritizing sites. To provide a starting place for others trying to locate a BMP monitoring site, the students decided to document their selection process in a general flow chart.
5) Project Costs - For the proposed BMP design, students developed a cost estimate for construction, equipment, material, fabrication, and monitoring operational costs.
6) Sustainability Evaluation - The student team identified and summarized the potential impacts of implementing a BMP monitoring system on the sustainability of the region's water resources. The student's summary indicated BMP monitoring supports sustainability efforts.
7) Project Reports, Documents, Publications, and Presentations - During the course, the student team was required to develop three technical reports; a beginning of project proposal, an interim design report, and a final design report. For this project, students replaced the interim and final report with the development of a draft QAPP; the same document professionals are required to prepare in preparation of stormwater monitoring projects. Preparation of a QAPP also supports compliance for Spokane County with the minimum control measures, specifically Post Construction. At the end of the semester, Gonzaga University hosts a Senior

Design Exposition event for students, faculty, and the industry liaisons where students present their final designs on a poster display and during formal presentations. For this project, the student team prepared their poster display in a format similar to the EPA fact sheets, which local regulators commonly to meet the minimum control measures, specifically Public Education.

Research Methods and Participants

The objectives posed as research questions in this paper were assessed using multiple methods, which included; comparing the case study activities with ABET program objectives shown in Table 3 and identifying which outcomes have been met or enhanced by completing the project tasks, reviewing notes from weekly student project meetings, and surveys completed by the first year students as well as the municipality industry liaison. Three different open-ended surveys were administered, as shown in Table 4. The first two surveys were conducted to assess the current case study and were completed by students taking the class (n=4) and the industry liaison engineer (n=1). The third survey was conducted to consider how future similar projects might benefit municipalities and was completed by stormwater practitioners (n=13), which included the industry liaison. The thirteen respondents are all engineers who serve in a stormwater management or a leadership capacity for a government agency regulated by or responsible for regulating NPDES stormwater permits. The agencies represented include a mix of local and state governments located in Washington, Idaho, Oregon, and North Carolina. Surveys were anonymous and administered via survey monkey for the stormwater managers and outside of the regular class time for students. Qualitative analysis of the data included: transcribing the data, compiling the responses by data source and question, coding the data to determine patterns within the responses, and then regrouping the responses into themes. Once the main researcher completed the initial analysis of the data, another researcher reviewed the themes in comparison to the data responses. Ultimately, both researchers agreed on the coding relative to the content and general themes.

Table 3. ABET Program Educational Objectives

a.	Ability to apply mathematics, science and engineering principles.
b.	Ability to design and conduct experiments, analyze and interpret data.
c.	Ability to design a system, component, or process to meet desired needs.
d.	Ability to function on multidisciplinary teams.
e.	Ability to identify, formulate and solve engineering problems.
f.	Understanding of professional and ethical responsibility.
g.	Ability to communicate effectively.
h.	The broad education necessary to understand the impact of engineering solutions in a global and societal context.
i.	Recognition of the need for and an ability to engage in life-long learning.
j.	Knowledge of contemporary issues.
k.	Ability to use the techniques, skills and modern engineering tools necessary for engineering practice.

Table 4. Student and Municipality Partner Survey Questions

Student Survey	
1.	What do you like best about this course?
2.	What do you like least about this course and what changes could improve your learning?
3.	How satisfied are you with the design experience you are having on this project?
4.	How do <u>you see your project</u> compared to other students senior design projects?
5.	How do <u>other students see your project</u> compared to their senior design project?
6.	How do <u>you see other students</u> project compared to your senior design project?
7.	How do <u>other students see their</u> project compared to their senior design project?
8.	Any additional comments?
Municipality Liaison Survey	
1.	Describe how this project will help your agency meet NPDES permit requirements.
2.	Before the senior design project started what were you anticipating for a final deliverable (at the end of the school year)?
3.	Based on the students' progress to date, indicate how satisfied you are with the student's progress. Explain your reasons.
4.	What can the students do to improve the project in the spring semester?
5.	What can the instructor do to improve the project in the spring semester?
6.	What could you do to improve the project in the spring semester?
7.	If a consultant did this project, approximately how much would it cost your agency?
8.	Do you think it will take more or less of your time to work with the students on this project compared to consultants doing a similar project?
Stormwater Manager Practitioner Survey	
1.	Has your agency ever worked with students at a university on an engineering project? If yes, indicate education level (i.e. graduate or undergraduate).
2.	With respect to stormwater, what would you need from an undergraduate student project to make it worth your agencies time to collaborate with a university?
3.	What (if any) concerns do you have in working with undergraduate students on a stormwater project.
4.	Specific to undergraduate projects, what do you think are the key components to a successful partnership between a university and your agency?
5.	What would you like new engineers to know about stormwater before they graduate?

Assessment and Discussion

<u>Meeting the Program ABET Objectives</u>

As shown in Table 5, completion of the project tasks described in this case study allows the project to support the ABET objectives in every case except global awareness. This indicates that this type of real-world project can satisfy the educational needs of the student and the university. In addition, there are three important attributes of this case study project that we believe "enhance ABET outcomes (shaded in grey in Table 5)" by providing students with a more in depth experience and therefore achieving a higher-level outcome when compared to meeting just the desired ABET program outcomes:

1. The important feature of designing an experiment to monitor the effectiveness of a bio-infiltration pond.

2. Understanding of stormwater codes and regulations and the current state-of-practice using the literature review. In addition, the incorporation of the NPDES requirements and data collection into the QAPP required that the students collaborate with local stormwater agencies and managers to produce a practical and effective design.
3. Preparing technical documents that support the minimum control measures described in Table 1 including; a manual for the monitoring effort by future students, a QAPP describing the BMP monitoring study, and a fact sheet summarizing BMP monitoring for public education.

The information gathered during the project data collection (Task 2) is critical to guiding the design process, enhancing the life-long learning skills of the students (enhancing outcome i), and allowing the students to comprehend contemporary issues in stormwater system design (enhancing outcome j). The design of a bio-infiltration pond and associated monitoring system also requires the students to develop a set of experiments that can be applied consistently by future students to monitor the effectiveness of the pond (enhancing outcome b). Finally, the students must effectively communicate with local stormwater managers to ensure that their design is meeting jurisdictional needs (enhancing outcome g). Overall, this senior design case study project satisfies the necessary ABET student outcomes, while allowing the students to achieve a few of the outcomes (b, c, g, i, and j) at a higher level when compared to other capstone design project efforts.

Table 5. ABET Outcomes Satisfied by the Case Study

	ABET Outcome										
Project Task	**a**	**b**	**c**	**d**	**e**	**f**	**g**	**h**	**i**	**j**	**k**
1) Project Management			X	X		X	X		X		X
2) Project Data Collection	X	X		X	X	X			X	X	X
3) Pond and Monitoring System Design	X	X	X	X	X	X			X	X	X
4) Select Installation Site	X			X	X	X			X	X	X
5) Project Costs	X			X		X			X		X
6) Sustainability Evaluation				X		X			X		X
7) Project Reports, Publications, Presentations				X		X	X		X		X

<u>Student Assessment</u>

All students indicated they were satisfied with the design experience and described the project as "unique", however some felt that a design focus only on a monitoring system was too narrow. The students liked participating in a practical real world project and the aspect of project they most enjoyed was that the project was located on campus, which allowed them to visit the sites and visualize the design. While all students indicated the literature search or research portion of their project was helpful, they also indicated they were anxious to start on the design and some felt there was too much research.

In comparison to other senior design projects, students described their project as "new" and "different" allowing them to "come up with something of our own". The students described other projects as either a "direct extension of class" or "designs that has been done before".

Students also felt their project was more "challenging" than other projects because there were no examples to follow; however, they also felt the project lacked specific guidance that they observed with other project teams. In response to other student's observations of their project, they all indicated most students "don't quite understand until we have a chance to explain why it's important" or "students are just overwhelmed" when they try to explain it.

In addition, all students provided recommendations for the course that included an opportunity for more "hands on" activities. Two of those students suggested that this could be achieved by having the course include students building and testing a monitoring system prototype.

Student indicated that including tasks common to stormwater practitioners (i.e. QAPP) in the capstone design course was motivating to them and provided them with a valuable practical experience. With regard to having the capstone course focused on a real world stormwater project, students provided mixed responses. Specifically students had to develop design guidance for the monitoring system based on a literature search and anticipated NPDES permit requirements. Some students indicated they enjoyed this challenge; others were frustrated with the unknown aspects of this part of their project.

Industry Liaison Assessment

The industry liaison indicated that he was "extremely pleased with the progress the group has made" and felt that the student's reports and presentation reflected their hard work. In consideration of how the student project might provide future value to the municipality, the liaison engineer indicated that since the final monitoring system design would help support municipality compliance with future NPDES permit requirements for BMP effectiveness monitoring. In consideration of how the student project will provide value to the municipality, the liaison engineer indicated that the agency was planning to include the student project in their stormwater annual report, which is required by the NPDES permit to include all stormwater monitoring related studies conducted by the municipality. With respect to the amount of time, the liaison spends on the project to mentor students, he felt it was equivalent to the time he would have spent working with a consulting company on a similar project.

Stormwater Practitioner Survey

Of the 13-stormwater practitioners who responded to the survey, 10 indicated they have collaborated with a university on a student project, with only 2 indicating they had not and 1 did not respond. Of those who indicated they had worked with students on a project, 10 had worked with undergraduate students and 6 had worked with graduate students. *Note responses often exceed 13 because the respondents provided multiple answers to some questions. In the following section, the number of responses for each theme is identified in brackets.*

With respect to what stormwater practitioners needed from student projects to make them worth the agencies' time, the most significant responses were project deliverables that provided value to the agency by meeting current agency needs (7), followed by agency time to support the project (4), and value to student learning (3). Two respondents indicated they had inconsistent success with the quality of student projects where some were well done and others were not. For the future, these respondents indicated they wanted to see consistent professor guidance on student projects and felt that would ultimately lead to student success that is more consistent on future projects.

With respect to concerns municipality identified for collaborating on undergraduate student projects, an overwhelming number of respondents indicated concerns regarding lack of students skills to complete a quality final product (8), followed by the agencies available time to mentor students (5), and the required project timeline not aligning with the academic year (3). Finally, recommendations for new engineers with respect to stormwater skills focused on a better understanding of the BMP function and treatment process.

Future Plans and Considerations

Post construction plans for this project include; a second capstone design project and integrating the BMP monitoring activities into other civil engineering courses. Each section describes; how the project might align with the course objectives, recommendations for expanding the student's stormwater experience, and how the monitoring activities support NPDES permit requirements.

Year 2

In the fall of 2014, a new team of capstone design students will begin monitoring the BMP which includes; collecting and analyzing stormwater influent and effluent samples. The primary goals for this project include; 1) evaluating the different monitoring system designs (for collecting representative stormwater samples), 2) recommending design guidance for infiltration BMP monitoring systems, 3) evaluating the pollutant reduction performance of the BMP, and 4) refining the training manual for future student monitoring. In addition, if the BMP pollutant reduction performance does not demonstrate the BMP meets permit requirements, the scope of the student's project may expand to include recommendations for modifying the current BMP design guidance. The second year of the project should provide similar ABET outcomes as year one and also provide Spokane County with information in preparation for future NPDES BMP effectiveness monitoring.

Year 3 and Beyond

Guided by the training manual produced in years 1 and 2, the BMP will provide an outdoor laboratory for students in other courses. This section identifies civil engineering courses where monitoring activities could support the course objectives. The basis for selecting the courses noted below includes; previous studies that indicate BMP monitoring was successfully integrated into similar courses[23-26] and the monitored BMP function and treatment mechanism align with the fundamental concepts covered in the course[8,30].

- Environmental Engineering Lab - In this course students learn about fundamental environmental chemistry principles and analytical techniques used to study water quality and treatment process performance. Students in this course will evaluate the pollutant reduction ability of the BMP provided by the primary treatment mechanisms; filtration, plant uptake, and soil sorption. The specific monitoring activities for this course include; collecting stormwater influent and effluent samples, testing the water quality of each sample at the university lab, and calculating the percentage of each pollutant removed by the BMP. Water quality testing will focus on the regional stormwater pollutants of concern such as; hydrocarbons, nitrogen, dissolved metals, total suspended solids and phosphorus.

- Hydrology - In this course students learn the basics of hydrologic design including: statistical methods, rainfall analysis and design storm development, frequency analysis, peak discharge estimation, hydrograph analysis and synthesis, flow routing, and risk analysis. Students in this course will focus monitoring on stormwater quantity reduction. The specific monitoring activities for this course include; surveying the contributing area and the BMP, collecting precipitation data, locating soils maps, and measuring the actual flow rate and volume into the BMP during a storm event. The collected data could then be used to conduct a pond routing analysis. In addition, a risk analysis could also be conducted by comparing the analysis from actual data to an analysis using the regional design storms and guidance.
- Soil Mechanics Lab - In this course students learn about laboratory and field methods for evaluating properties and the behavior of soils under various environmental conditions. Students in this course will the focus monitoring activities on stormwater quantity reduction. The specific monitoring activities could include determining the BMP infiltration rate using different in-situ testing methods.

Findings and Conclusion

This paper presented a case study focused on the first year of a cooperative stormwater project, which provided the basis for assessing the potential benefits to the participants, the university, the municipality, and the students. This case study is part of a multi-year collaborative project with the goal of expand opportunities for students to develop stormwater engineering skills within the current university curriculum by aligning student activities with NDPES permit requirements and having students prepare technical documentation consistent with the EPA requirements for stormwater management projects across the country. Assessment of the case study focused on the applicability of the project to meet required learning outcomes as well as survey responses from students and the industry liaison. In an effort to consider how future similar projects might benefit municipalities, a national stormwater practitioner survey was also conducted. In addition, this paper provided recommendations for integrating the BMP monitoring into other Civil Engineering courses.

Based on an evaluation of the data provided it appears this type of collaborative project can benefit all partners. However, considering the case study focuses on the experiences of four students and one liaison engineer over a single year, additional research is needed to determine if these findings are scalable and could provide similar benefits for an entire class conducting the monitoring activities described in the future plans section of this paper. While other universities have utilized BMP monitoring as an outdoor laboratory, most focus on aligning the monitoring activities with the course objectives and few consider how students can develop practical stormwater experiences by aligning the monitoring activities with NPDES permit requirements. The research questions and specific findings are summarized in the subsequent section.

1. How can the capstone design course objectives simultaneously meet ABET requirements while also providing students with an increased opportunity to gain experience and skills common to stormwater practitioners?

   The capstone design course objectives for the case study not only fulfilled ABET requirements but in some areas also provide student with more depth when compared to ABET outcomes. Specifically, the expanded literature search provided students with an opportunity to develop techniques that support lifelong learning skills[22]. The project also provided students with stormwater experience that supports three of the six minimum control measures required by the NPDES permit. Based on student responses, students were satisfied with the project design experience; although additional guidance may be required for projects with greater research aspects, specifically where students are defining the design based on a literature search.

2. How can a partnership between a university and municipality best support educational outcomes and meet NPDES permit requirements?

   Meeting educational outcomes and providing students with a meaningful learning experience was a top priority for this project, which required some adjustments to the project scope during the year to ensure the students can produce meaningful work products during the course. From that, consideration was given to how the project aligned with NPDES permit requirements and provided value to the industry. Stormwater practitioners indicated the key aspects of collaborative projects include good communication with the university, limited time comment from industry, and having a professor who is knowledgeable in both stormwater management and has a basic understanding of the project history. With respect to industry time comments on collaborative projects, the industry liaison indicated he felt his time supporting the student project was consistent with the time required for a consultant to develop a similar project.

3. How might integration of BMP monitoring support the objectives for other civil engineering courses and expand stormwater learning opportunities?

   Integrating BMP monitoring activities into civil engineering courses provides a meaningful way for students to apply practical knowledge of theoretical concepts. In addition, BMP monitoring has been documented by other Universities as a means of providing students with an outdoor laboratory where monitoring activities support the course objectives. Suggestions for expanding student stormwater learning opportunities can be derived from the Stormwater Practitioner Survey, specifically recommendations for new engineers to have a better understanding of the BMP function and treatment process. This could be accomplished by expanding the monitoring activities to include additional instruction on BMP function and treatment mechanisms as well as the role of monitoring with respect to stormwater policies.

4. What do municipalities need from capstone projects to make the project valuable to them? The value perceived would act as incentive to support this type of future projects.

The stormwater practitioners surveyed identified their top priorities as projects that provide value to the agency on a timeline that meet their needs, with good professor guidance and limited time requirements from the agency. With respect to providing value, it appears projects that result in students developing documents that align with the six minimum control measures could be valuable to stormwater practitioners. In comparison to the industry liaisons positive responses on the case study, it appears similar projects could provide value to other municipalities. In addition, university professors assigned with mentoring students on stormwater projects should be both knowledgeable about the project history as well as stormwater management.

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