Introducing Engineering to Elementary School Students through Flood Mitigation in School Property

I. Project Description

A local elementary school within the jurisdiction of County X was experiencing frequent flooding. County X approached our university to develop a solution for this problem. This was assigned as a senior capstone project to a civil engineering design team. The team was asked to (i) incorporate green stormwater infrastructure (GSI) techniques to alleviate flooding and modernize stormwater infrastructure, and (ii) explore educational opportunities for elementary school age students to educate them about engineering through hands on experience. *GSI refers to using vegetation, soil and other natural systems to control and manage stormwater systems*.

To avoid confusion, elementary school students are referred to as 'students' and team of civil engineering undergraduates who worked on the project are referred to as 'team' or 'design team'.

Background

The PreK-5 school was built in 1985 and educates a little over 300 students. Figure 1 shows the aerial photograph of the school site (on left) and the types of ground cover of lot (on right) analyzed using Geographic Information System (GIS). The school lot is about 10.9 acres, with 50% impervious surfaces, 28% forested area, 21% lawn and 1% pasture. The area receives an average annual precipitation of 40.7 in.

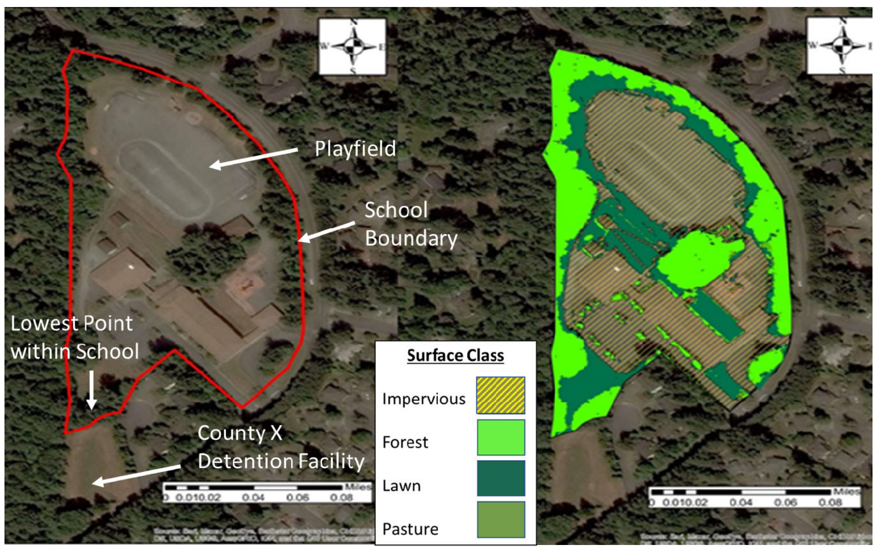

Figure 1. Aerial View of Project Site: school (left), ground cover (right)

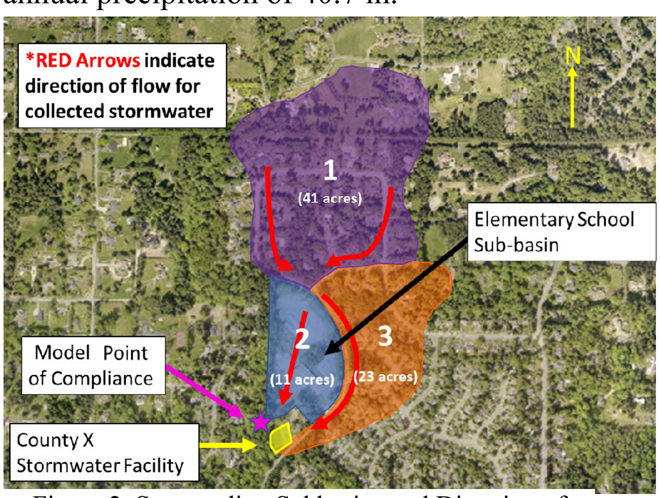

Figure 2. Surrounding Subbasins and Direction of Stormwater Flow

The school is part of an 85-acre drainage subbasin with a north-south slope, as determined by GIS and the county mapping system, and presented in Figure 2. Currently storm water within the school subbasin (Area 2 of Figure 2) is captured through a mixture of catch basins and French drain systems. Stormwater runoff from the entire 85-acre subbasin is combined and routed through 0.4-acre lawn area in the southwest corner of the site, where it enters the County X storm water facility (a detention pond). This detention pond collects stormwater during large storm events (exceeding 25-year storms). However, during small storm events, the stormwater from the school bypasses the detention pond and results in flooding within school property.

Preliminary Research and Data Collection
The design team visited the site with an engineer from the county and the faculty advisor, both PEs, to collect site topographic data and define project issues and constraints. Thereafter, the team researched the geology of the area and studied the water percolation testing done at the project site by the county to determine the feasibility of underground injection control wells as a mode to control flooding. The information collected was vital in performing hydraulic modeling and in selecting site appropriate green stormwater infrastructure best management practices (GSI-BMPs). The team also researched several GSI-BMPs, their pros and cons, and the suitability of each technology for this specific project site.

The project had multiple stakeholders: County X, elementary school faculty, staff and students, school district facilities technicians, and a surrounding neighborhood homeowners association (HOA). Engaging all these stakeholders was an important aspect of the project. The team developed an interactive web-based survey that included photos and videos of different GSI technologies and sent it out to the students, faculty and families of the school and to the HOA. The purpose of the survey was to gather information on how the school and its surrounding area were currently being used and to receive feedback on potential GSI-BMPs and where they could be implemented.

The team used a regional specific hydrologic model to study the flow conditions prior to development of the area, current condition and after retrofit options are implemented to mitigate flooding. The team also used regional climate change models to modify the input precipitation data and compare how the system responds to pre and post retrofit conditions.

Development of Alternatives
Based on the above findings, the team developed three alternatives:
Option 1 - Sand Filter: Route stormwater from Sub-basin 1 (of Fig 2) into a wet vault and a sand filter combination constructed underneath the play field (shown in Fig 1).
Option 2 - Bioretention Cells: Treat the storm water from Sub-basin 2 (of Fig 2) at southwest corner of the school (labeled 'lowest point' in Fig 1) through terraced bioretention cells with outdoor educational classroom opportunities for students.
Option 3 - Detention Pond: Increase the capacity of County X's detention facility (of Fig 1 left) to accommodate all flow from Sub-basins 1 to 3 (of Fig 2).

Illustrations of the three options are not presented in this write up due to space restrictions but are shown in the poster.

The team analyzed the above three options for the following:
- **environmental lifecycle costs**: *Lifecycle Costing Module for Distributed Stormwater Control Measures,* an MS Excel workbook, was used to study lifecycle impacts. The results were expressed as carbon dioxide equivalents and eutrophication (*excess nutrients from*

stormwater runoff causing low oxygen levels in water bodies) expressed as kg of nitrogen equivalents.

- **environmental benefits**: *National Stormwater Quality Database* and a *hydrologic model* were used to determine the kg of pollutant (eg. copper, zinc and total suspended solids) removal per year.
- **cost**: computed as the sum of construction, construction management, project management, contingencies, capital cost and operations and management cost.

The team also investigated PreK-5 educational opportunities and challenges for each of the three options.

Based on the findings, Option 2 - Bioretention Cells, was selected as the preferred option. The preliminary (10%) design of this option is shown in Figure 3. The team took this chosen option to a 30% design.

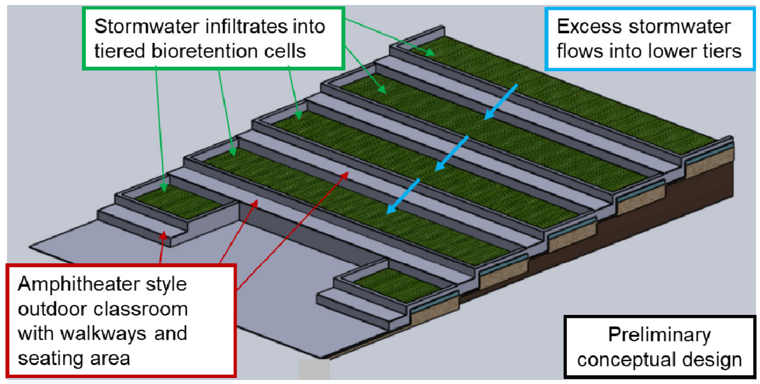

Figure 3. Preliminary Design of Preferred Bioretention cell option

30% Design of Bioretention Cells

Figure 4 shows the detailed design of the bioretention cell option developed by the team. This will be located at the lowest point of the southwest corner of the school. The bioretention cells were adjusted to closely fit the topography of the site to minimize the cut and fill quantities.

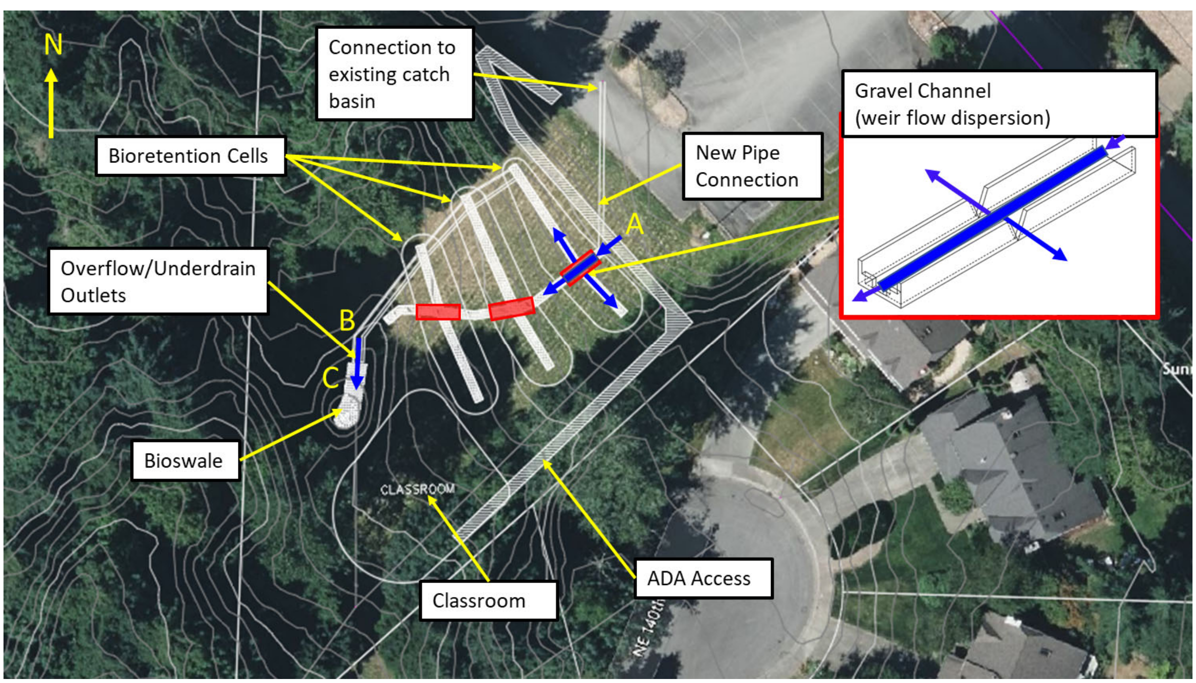

Figure 4. Design Details of Bioretention Cells, the Preferred Option

As shown in Figure 4, stormwater from the catch basin underneath the parking lot and the surface runoff is routed into the bioretention cells at point A. Water flows downslope through a cobble channel and is dispersed laterally into bioretention cells through 45º V-notch weirs as shown in the Fig 4 inset. Excess water that is not dispersed laterally continues downstream through a rectangular weir feeding into two more tiered bioretention cells in the same manner. The weirs were sized such that water will flow into uppermost bioretention cells even during small storm events. The entire system was designed using the regional surface water manual to handle a 100-yr flow of 5.2 ft^3/s.

Each bioretention cell has a lateral slope of 1.5%, 1V:1H side slope and a maximum ponding depth of 12 in. The bioretention cells consist of 2.5 ft of engineered soil with adequate permeability, 2 ft of drain rock with a 6" diameter underdrain PVC pipe. The underdrain pipes daylight onto a cobblestone channel for energy dissipation (point B in Fig 4) and enters a bioswale (point C in Figure 4) before exiting the school property into the county stormwater facility (shown in Figure 1). The bioretention cells and bioswales remove pollutants from the stormwater. An ADA (American Disability Act) compliant access ramp wraps the northeastern and southeastern edges of the bioretention cells making the site universally accessible as shown in Figure 4.

The team provided the county with supporting calculations and engineering drawings for the entire system, some of which are presented in the accompanying poster.

Educational Activities for PreK-5 Students

The design team researched age-appropriate educational activities that could be incorporated into PreK-5 curriculum to introduce engineering to students. Figure 5 shows a map of the activities. These activities and student learning objectives are described below:

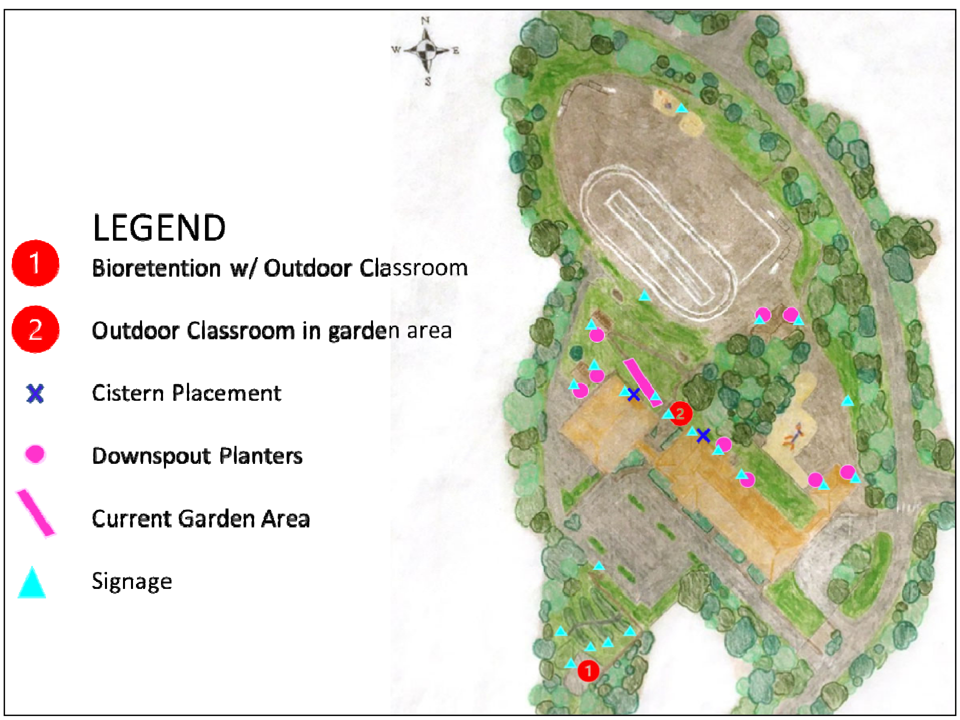

Figure 5. Educational Opportunities for PreK-5 students

<u>Outdoor classrooms (at Bioretention cells and garden area)</u>:

1 2

- Select different water-tolerant, native vegetation for each tier of bioretention cell and garden area; *students learn* *about ecosystems, climate, plant types*

- Sampling of stormwater at entry and exit points of bioretention cells; *students learn about water quality changes through GSI-BMP.*

Rainwater Cisterns:

- Collect rainwater off roofs in two 1000-gallon cisterns with sight glass on side; *students measure rainfall, use rainwater to water planter boxes and eventually use cistern water for toilet flushing.*

Downspout Planter boxes:

- Place planter boxes where leaks have been reported and at downspout outlets; *students learn about choosing appropriate vegetation for planters and plant growth, and water reuse.*

Signage:

- Place informational signage throughout school about stormwater features (bioretention cells, downspouts, gutters) and vegetation (native species, water tolerance of plants); *students learn about stormwater flow, water quantity/quality/reuse, and ecology.*

Cost Estimate and Construction Recommendations

As part of the 30% design the team estimated the cost using state department of transportation bid tabs. The cost included site preparation (clearing and grubbing), site formation (excavation, grading, hauling, plants and materials, erosion control) and contingencies. The team arrived at a total cost of $940,000.

Because the project disturbs more than 2,000 sq ft of land area, it required a temporary erosion and sediment control (TESC) plan to be implemented during the construction phase. The team developed the TESC plan which involved construction vehicle exit points and control of stormwater to the site to prevent erosion, high visibility fence and construction area and parking area stabilization. Furthermore, the team recommended that construction be scheduled during July-August because school not being session is beneficial to student safety and low precipitation makes it easier to route stormwater flows during construction.

II. Collaboration of Faculty, Students and Licensed Professional Engineers

All engineering undergraduates in our university complete a year-long capstone project for an external sponsor. A team of five undergraduate seniors worked on this project under the supervision of three liaisons from the county of which two of them are PEs and a faculty member from the university who is a PE. In addition, the senior design course is taught by a PE. The team met weekly with the faculty advisor and had weekly conference calls with the county liaisons. The faculty members and the liaisons provided feedback on the proposal, design and final report throughout the academic year.

Our department has an active advisory board consisting of licensed, local civil engineering practitioners that meets twice yearly to discuss industry-academic partnership related issues. The team made an oral presentation to the board early in the academic year describing their project scope and plan of action.

The team participated in a presentation competition organized by a local professional society. The presentations were judged by a panel of civil engineering PEs.

The team presented their work to the county twice. Early on in the academic year they presented their project understanding and approach; at the end of the academic year they presented their completed work and recommendations. Diverse groups of professionals attended these presentations. The team found these presentations to be quite challenging due to the extensive knowledge and experience of the audience and the questions asked but found it to be a great career growth experience.

III. Protection of Health, Safety and/or Welfare of the Public

Throughout the project the design team was focused on the safety and welfare of the PreK-5 students. As shown in Figure 4 the bioretention system was designed with retaining walls that are of age-appropriate height, ramps that make it universally accessible for students and the whole system that provides a safe environment to students when they collect stormwater samples for testing. Furthermore, the team recommended to the county that construction take place in summer when the school was not in session.

IV. Multidiscipline and/or Allied Profession Participation

The project involved a broad gamut of disciplines: water/environmental engineering, plant ecology, cost estimation, construction management and PreK-5 science/engineering education. In addition, the design team had to generate surveys that were clear to a broad audience, reach out to the surrounding community to receive feedback, and collect and analyze the survey data.

The project involved multiple stakeholders which gave the team an opportunity to interact with individuals outside engineering. One of the liaisons from County X was a drainage basin steward with a background in K-12 education. In her role as the link between the county and the elementary school, she helped the design team to meet with PreK-5 science teachers and the head facilities manager of the school to discuss the feasibility of implementing different GSI techniques and input in developing age-appropriate educational modules. She also facilitated the development of surveys by the design team that had to be understood by the PreK-5 students as well as surrounding homeowners association members, teachers, and administrators.

V. Knowledge or Skills Gained

Through this project experience the undergraduates developed a wide range of knowledge and skills: technical expertise, communication and project management skills, ability to work in a team setting and to interact with stake holders who are non-engineers. The team also learned how engineering could be introduced to PreK-5 students through engaging activities.

a) Technical Expertise Gained

The team used a wide range of tools to accomplish the goal of the project. They acquired skills and working knowledge in the following:

- <u>Engineering Documents</u>: Various literature on Stormwater Best Management Practices (BMP) and Green Stormwater Infrastructure (GSI) techniques from various jurisdictions, County Surface Water Design Manual, RS Means Cost Indices.
- <u>Design/Computer aided drafting software</u>: AutoCAD, Civil 3D for engineering drawings.

- Literature on STEM education: on how to incorporate engineering in K-12 classrooms.

b) Communication Skills Gained

The team was required to make oral presentations to their peers twice a quarter. The academic year concluded with a grand virtual event where the team presented its work to the university community, sponsors of all capstone projects, prospective sponsors, friends, families and alumni.

Improving technical writing skills of our graduates is an important focus in our program. Hence, the team was required to submit a written proposal to the client at the end of fall quarter, describing the scope of work, plan of implementation, schedule and budget. At the end of spring quarter, they submitted a final report describing the work done, engineering calculations, drawings and other deliverables as initially agreed upon with the client.

Preparation of the surveys to stakeholders taught the design team how to communicate with a wide age group and with non-engineers. The surveys prepared by the design team consisted of figures where users could click and learn more about GSI techniques so that they could provide knowledgeable feedback on their preferred choices.

Due to the pandemic the project was completed entirely in a remote environment. The team used Zoom effectively for working sessions, meetings and presentations. The skills the team developed will be of value in the post pandemic and global work environment where virtual or hybrid work will be more common.

c) Project Management skills Gained

Each team member played the role of a project manager for part of the academic year and had the following responsibilities: setting up team meetings, developing meeting agendas, conducting the meetings, assigning tasks to the team members and following up on action items. In addition, the project manager was in charge of contacting the client, the liaisons, and the faculty advisor in between team meetings, as necessary.

d) Engineering Awareness among PreK-5 students

The team enjoyed the aspect of creating teaching modules to introduce engineering to elementary school students through hands on experience.

VI. Summary

County X mentored a team of civil engineering seniors to develop a solution to flooding in a local elementary school. As part of the project, the design team also developed age-appropriate education modules that could be incorporated into the PreK-5 curriculum exposing students to science and engineering through hands on activities. Three county personnel served as professional mentors to the team – two of them PEs and one with a K-12 education background. The project was supervised by two faculty members, both professional engineers. In addition to developing technical and professional skills, the team learned how to communicate with a broad range of stakeholders.