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Integrating Ecology and Sustainability into Civil Engineering Design: A Civil Engineering Capstone Project

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Abstract

Because of the increasing demand from the industry to develop sustainable solutions, it has become essential for engineering educators to teach students the knowledge and skills to engage in sustainable design. The application of sustainability principles when considering physical structures can lead to the formation of more sustainable solutions to various civil engineering issues. Erosion control is one of the situations where ecology would be most useful. In this project, a nature center located in northwest Ohio is home to 109 acres of natural forests and farmland, has been experiencing erosion problems from water runoff. Students were tasked with designing an erosion system to prevent runoff and manage stormwater. It is easy to become engrained in the traditional grey infrastructure solutions that have grown so common in society. Instead, the team developed a design that contributes to the natural ecology of the site and constructs a new sustainable habitat for the wildlife in the area. To construct this new green solution, the team chose to incorporate a multitude of grass swales, check dams, and adaptive vegetation. The adaptive vegetation and grass swales are used to create new habitats for the wildlife around the site, which helps to make the site sustainable by providing more usable space and resources for the wildlife that live in the area. Check dams considered as grey infrastructure are constructed to eradicate the current runoff issue. The goal is to blend grey and green infrastructure solutions to develop a sustainable solution for the ecosystem and environment. This project not only requires students to apply the knowledge of Civil Engineering in designing the structures but also to learn about ecology to promote sustainability for the local community. This paper outlines the entire design process from conception to completion, with emphasis on problem definition, development of design concepts, interactions with stakeholders, and development of the detailed design. The project provides a design challenge that motivates and promotes students' problem-solving and independent learning skills as engineers, according to the assessment results and feedback from professionals regarding students' design outcomes. This project would be helpful to educators exploring Civil Engineering projects involving community engagement, sustainability, and multi-discipline engineering knowledge.

Introduction

The concept of sustainability is taking a more prominent role in Civil Engineering education all over the world. Sustainable development has been integrated into teaching and learning throughout the engineering education program in many universities. There is an increasing demand from the public to achieve a balance between environmental, social, and economic outcomes within sustainable development [1]. Therefore, engineers, especially Civil Engineers, should be able to respond to societies' concerns about the impact of human activity on the environment. Civil engineers are responsible for designing the critical infrastructure which provides the basic services that allow operations of modern communities [2]. However, recent events have shown infrastructure systems to be vulnerable to natural events because many

infrastructure systems are reaching the end of their intended design life. The ways in which these aging assets are replaced and refurbished provide an opportunity for the next generation of engineers, educated with sustainability and ecology principles at the forefront of their thinking, to provide smarter and more efficient ways of designing and delivering better services [3].

To prepare future Civil Engineers with sustainable thinking, approaches to teach sustainability concepts in the civil engineering curriculum also have been created. According to the ABET accreditation criteria for all baccalaureate-level programs, criterion 3(c) states that programs must demonstrate their students attain: "an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability." [4] Various approaches have been found to be successful through the assessment of sustainability knowledge and skills learned in activities, modules, and courses and across the civil engineering curriculum [5]. Among those approaches, integrating sustainability in the capstone design is one of the most effective teaching approaches. A capstone course is an integral part of Civil Engineering undergraduate education. It requires students to apply knowledge and skills acquired in earlier course work from a Civil Engineering curriculum in a design that solves real-world problems or mimics real-world projects [6]. Requiring students to address sustainability within the capstone design course can help prepare undergraduate students with some of the “knowledge, skills and attitudes necessary for entry into the practice of civil engineering at the professional level.”[7]. This paper describes how a capstone design team incorporates sustainability principles into their design. The data presented was taken from the student design reports and frequent assessments by professional advisors, faculty mentors, and the students.

Project Definition and Description

The Huston-Brumbaugh Nature Center (HBNC) is home to 264 acres of natural forests and farmland. Within these 264 acres, there is a northern 32-acre section of farmland across from the main parking lot that has been experiencing erosion problems from water runoff. The farmland is bordered on the south by a road and the HBNC parking lot. Heavy rains flow from the road and parking lot into the field. The field contains drainage pipes, but these pipes are severely undersized for the amount of water that enters the field. The HBNC has approached the team about fixing the erosion problems. Due to the parking lot being newly paved within the past five years, rain events have caused extra runoff that the current drainage system cannot handle. This runoff makes its way into the field and has caused an erosion trench through a path of low elevations. The student team is tasked with designing a sustainable erosion system that will serve as primary and secondary functions. The primary function of the system will be to control the erosion of the soil by controlling the flow of runoff. The secondary function of the system will be to create wetland habitats in the field.

The primary requirement and major focus of this project is that the final design must eliminate the rutting in the field that is caused by erosion. The field that the design will be implemented in is currently being leased to a neighboring crop farmer. The client wishes to end their lease agreement with the farmer and create wetlands on a portion of the field for future educational purposes. In the future, the client wishes to fill each wetland with different plant and animal life

to create different environments. For this reason, the creation of multiple, self-containing wetland environments was also a design requirement. This was the second most important requirement throughout the entire design. Along with eliminating erosion and creating multiple wetlands. The final project requirement is that the design must have the capability to drain all of the contained water. The client requested this function to ensure that the HBNC can control the water flow through our design. The client emphasized the need for this function so that maintenance can still be done in the wetlands to control species' inhabitants.

Design Description

1. Site investigation

Site investigation of the current field at the HBNC identified key features, including the under-road culvert, the inflow pipe for the existing field drainage system, the stream bed, and a general idea of the path and direction of flow in the field. Site investigation also identified locations for overflow parking and existing survey pins. The site investigation also identified a separate area of erosion approximately 50 yards to the east of the project bounds. The HBNC features the John D. Brumbaugh Visitors Center, the Bird Observatory, Koch Environmental Learning Center, as well as gardens and over 5-miles natural trails. These facilities and trails are open to the public with ample parking spaces. The land that this project is located on is a 20-acre field that is located across from the HBNC's parking lot. Figure 1 shows a Google Maps depiction of the HBNC's field.

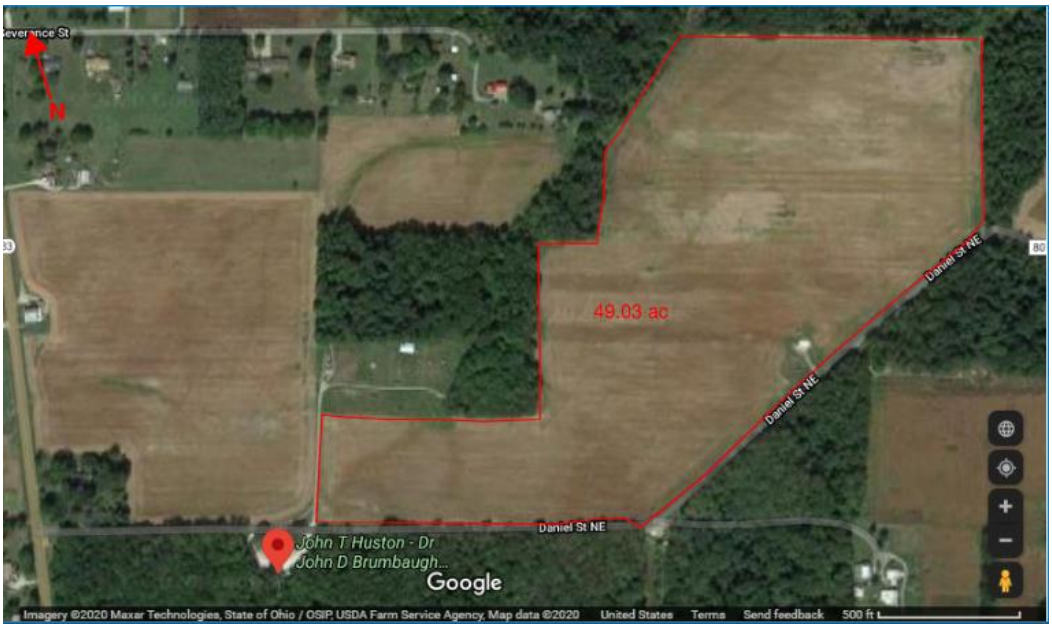

Figure 1. Nature Center Aerial View

The water that enters this field comes from multiple areas. One location that the water comes from is the HBNC parking lot which is located directly across the street from the site. Runoff flows from this parking lot into a ditch that is located directly across the street, adjacent to the parking lot. When the ditch overflows after a heavy rain event or snow event, the water crosses the road and enters the field. A second location that delivers water into the field in the southern

part of the HBNC. The woods that are located south of the site are at a higher elevation than the field. Water from the woods drains into the ditch that receives the parking lot's runoff. There is a pipe that is located under the road and drains from south to north in this ditch. When this pipe cannot handle the amount of runoff that occurs after heavy rains, the water begins to pond and eventually flow over the road and into the field. A third location that delivers water into the field is the road.

Figure 2. is an erosion hazard map, which shows the level of erosion hazard in different areas of the field our design will be put in. The different colors on the map represent the different levels of hazard erosion. Green represents areas that are least likely to experience erosion, yellow represents areas that may moderately experience erosion, and red represents areas that have or can experience erosion. The green areas shown on the map are high points, so there will not be a lot of water running through those areas. The red areas were the low spots of the field and where erosion has already taken place. The yellow areas were the in-between the green and red areas. These could potentially be affected during large rain events as well as runoff coming from the green areas. The different colored regions in the hazard map illustrate varying levels of hazards that are experienced in each section of the site.

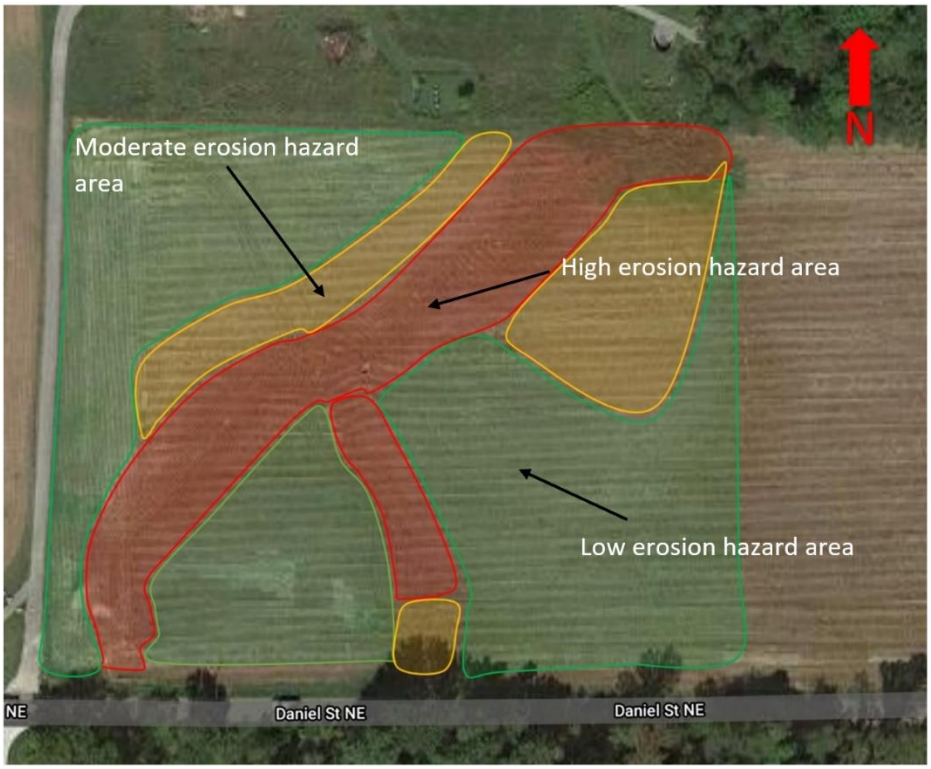

Figure 2. Erosion Hazard Map

2. Sustainable Design

The project has been challenging from a technical perspective but also rewarding in helping to create more habitat for the animals that call the project site home. Since the project was focused on runoff prevention and stormwater management, it was easy to become engrained in the traditional grey infrastructure solutions that have grown so common in our society, such as the

many dams and culverts. Instead of a common solution, the team developed a design that actually contributed to the natural ecology of the site and constructed a new sustainable habitat for the wildlife in the area. To construct this new green solution, the team tried to think outside the box when it came to construction methods and materials. For this project, students chose to incorporate a multitude of grass swales, check dams, and adaptive vegetation. The adaptive vegetation and grass swales that students incorporated allowed them to create new habitats for the wildlife around the site. By adding new habitat to the site, the site becomes more sustainable by providing more usable space and resources for the wildlife that live there. A site that contains an adequate number of resources for all of its wildlife is most often part of a sustainable ecosystem. As mentioned previously, students also included check dams in their design which will eradicate the current runoff issue, these check dams, since constructed out of concrete, would be considered grey infrastructure. The goal of the project was to blend grey and green infrastructure solutions to develop a sustainable solution for both our customers and the ecosystem. The final design of the check dams will rely heavily on grasses and other vegetation to create green soil retention via root systems. By designing these areas with specific ecosystems in mind, the final design will accommodate all sorts of species of amphibians, turtles, songbirds, and migratory waterfowl. Vegetation will be approved by the resident horticulturist to verify that it is native and ideal for the area in question when selected. Figure 3 illustrates a sustainable stormwater management system which is what students worked on modeling their design closely after. This project serves the surrounding community and adds a substantial amount of value to the surrounding site and ecosystem.

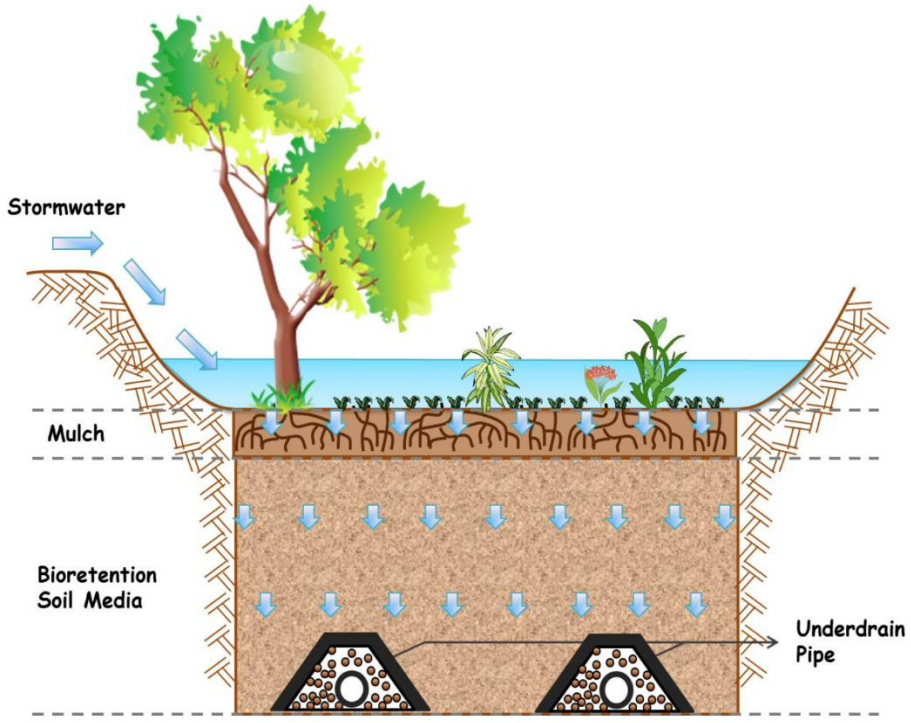

Figure 3. Stormwater Management System [8]

3. Check Dam Design

Each check dam holds a different level of water at a given time. For example, the first check dam would hold no water and just slowly release water as it entered, the second would retain 60% of the water that passes through, and the last would retain 80% of the water that passes through. The client would be able to control the amount of water retained by the height of the weir on the dam wall. This design will effectively stop erosion throughout the field while also creating a wetland habitat. The design will use the natural landscape of the field, plus three weirs, to create the layout that the client wanted. The weirs are the key component because they will be controlling the flow of the entire system.

Soil tests concluded that the soils in question are fine clays and loams. As such, the design of the retention system will only require check dams and rip raps to create a brake system on the flow from the road to the stream bed below. The erosion control method for this project will be a combination of soil check dams and grass swales. Dams will be constructed using reinforced soil berms extending across the line of flow with a central precast concrete section containing a weir and, in two of three dams, a gate valve for full drainage of the system. Each dam will be placed 193 feet away from the next to ensure equal coverage of the field. The final goal of these dams is to create three areas of standing water that, along with selected Ohio native vegetation, allow stormwater to enter and slow before exiting into the creek bed at the end of the system. Figure 4. shows the layout of the dams, and Figure 5 shows the CAD drawing of each dam.

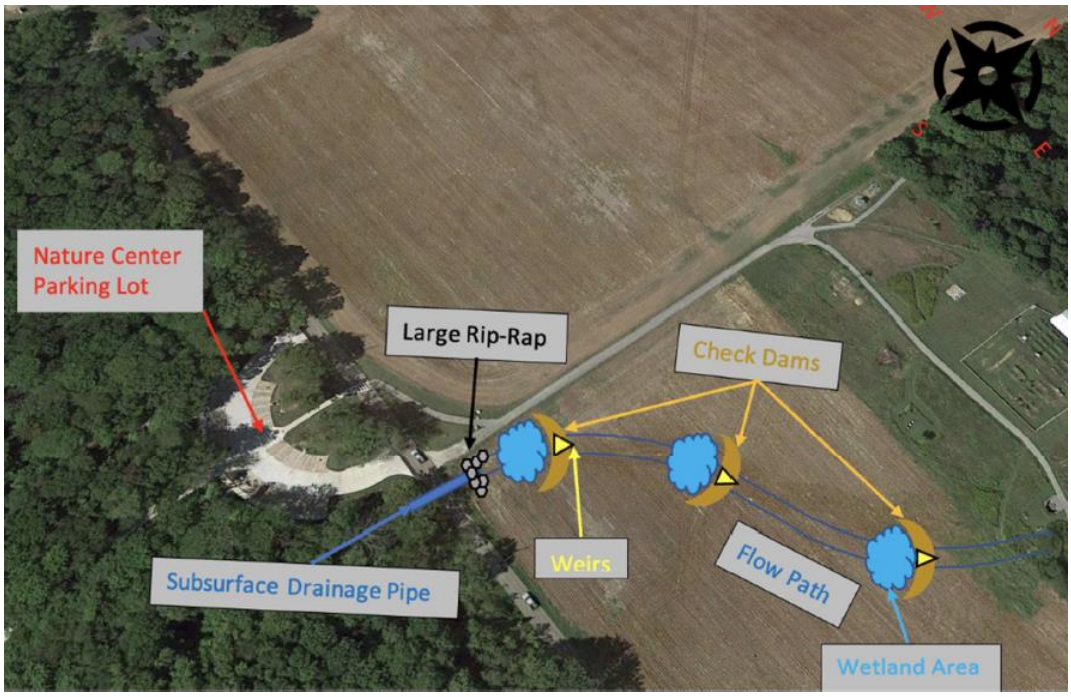

Figure 4. Check Dam Layout

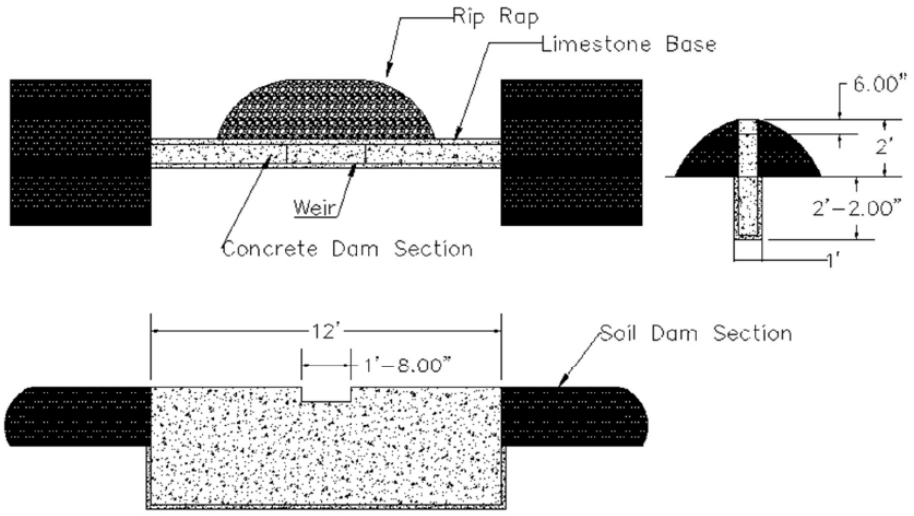

Figure 5. CAD drawing of a check dam

4. Environmental Impact

In this project, students developed a design that integrated both ecology and sustainability into it. The design incorporates both green and grey infrastructures to make the space a viable habitat for the surrounding natural life. Students incorporated native plants that have large shallow root bases that ensure the stability of the surrounding soil and also contribute to the health of the micro-ecosystem.

The implementation of this design will most certainly contribute in a positive way to the overall health of the surrounding ecosystem. The main goal of this design was to control the current erosion phenomenon that was happening at the site in question. One harmful side effect that could be realized because of this erosion is the transportation of harmful runoff downstream. The implementation of our design carries a secondary benefit of controlling not only the soil erosion but also the ability to be able to reduce the spread of this possibly harmful runoff downstream by trapping it behind the designed check dams.

The full-scale implementation of this design carries many benefits. One additional benefit not yet explained is the creation of additional habitat. The wetland space created will provide a prime location for many water-born animals in the region to thrive and reproduce. This area would be a prime location for salamanders to spawn and mature into adulthood. This design turns a once barren tract or land with major soil erosion problems into a thriving ecosystem for many types of aquatic life.

Assessment

A successful teaching approach requires effective methods for assessing student abilities to engage in sustainable design. Some work in the current literature has been done to analyze the conceptual sustainability knowledge of engineering students by using surveys [9]. To ensure that

students understand the complexity of sustainability topics and apply the knowledge in the design process, a sustainable design rubric has been proved to be a useful tool for capturing students' sustainable design abilities. In this project, students are required to use the rubric published in the existing literature [10]. This sustainable design rubric is a tool for evaluating project results, identifying areas for improvement, and justifying design decisions throughout a project's duration. It is a worksheet for instructors and stakeholders to record ratings and provide supporting evidence for each sustainable criterion. The first column names a criterion and provides a short definition. In the second column, the instructor and stakeholders should enter the total points earned out of 3 for each criterion. In the last column, considering the three dimensions of sustainability, Environment, Society, and Economics, students should provide evidence/examples to support their own design. Table 1 shows the design evaluation rubric.

Table 1. Sustainable Design Rubric

Criterion	**Evidence/Example**	**Earned Points (out of 3)**
Environmental Category		
Minimizes the use of non-replenishable raw materials; requires minimal energy input or uses renewable energy sources	#1: The check dams for our project will not consume any energy #2: We have not assessed the life cycle of the check dams for our project, we have only been focused on the erosion part of the project #3: Installation of grass swales minimizes the amount of concrete needed for the project.	2
Minimizes quantity of consumable waste (e.g., water, materials) output; manages quantity and quality (benign, usefulness) of waste	#1: The majority of the work on the project involves the use of soil already on site. #2: This project will greatly increase the quality of runoff water from the site. #3: This project reduces the quantity of runoff from the site, which will minimize runoff reaching the downstream watersheds.	3
Protects or enhances natural ecosystems (water, air, soils, flora, fauna, etc.)	#1: The project, after completion, will create a wetland habitat. #2: The life cycle of the wetland habitats will last if runoff is retained in the system. We analyzed weather data for the area. There is a good amount of rain that falls in the area. #3: Analyzed three different forms of water retaining systems to help control erosion: retention pond, grass swales, and check dams. Each is sustainable design and would help preserve the local environment.	3

Social Category		
Identifies and engages stakeholders in the design process	#1: Consulted with Nature Center staff on every aspect of design. #2: Provided Nature Center with a list of design concepts for final design selection. #3: Ensured design sustainability to promote long-term benefits for stakeholders. (Long term use of additional education space provided by the project)	3
Addresses needs of diverse stakeholders, acknowledging culture and other differences among individuals and groups	#1: After completion of the project, the new site will partly be used for early childhood education. #2: The relative closeness of the HBNC to Alliance allows a diverse group of students to access the resources it provides. #3: The Project will benefit the university in fixing the erosion issue that must be continuously repaired. And it also benefits the Nature center by having extra green space. The local educational systems in the area will also benefit from having new educational opportunities.	3
Protects human health and physical safety of users and society	#1: Increases water quality downstream, which promotes the health of wildlife and people since this water could end up as a drinking supply #2: This design includes nothing that could be of harm to people. #3: This design will improve the rutting from the erosion of the field. This makes walking through the field much safer. The ruts are currently tripping hazards.	2
Promotes human well-being and enhances quality of life for users and society	#1: Provides additional outdoor education space. #2: Provides visually appealing outdoor space. #3: Reduces polluted runoff downstream, which increases the quality of life for people downstream of the project.	3
Economic Category		
Evaluates economic impacts of environmental design criterion	#1: This design will allow the nature center to have more education space to attract more visitors (create more jobs/increase revenue). #2: The design will fix the erosion problems in the field, which will decrease the amount	2

	of maintenance that is required on the field. This will in turn save the nature center money. #3: The design creates new possible sources of revenue through education programs	
Evaluates the economic impacts of a social design criterion	#1: The educational benefits of the HBNC will spark youth early in education to learn more about the science of the world around them and attain higher educational levels. #2: Creating educational spaces closer to the Alliance, Marlington, and Westbranch school districts will save the school transportation funds. #3: The wetlands that will be created in this design will provide more opportunities for university's various programs to conduct projects and experiments in.	2
Considers affordability for users and/or demonstrates cost competitiveness or cost reduction for client/sponsor	#1: Implements green infrastructure, which is inherently cheaper. #2: Final design was the cheapest of our design options and should require very little maintenance	3
Evaluates economic costs and benefits to inform decisions	#1: Final design was the cheapest, thus making it the most feasible for the client who is on a tight budget. #2: Will limit overflow parking opportunities originally existing on the field edge. #3: The design will destroy a portion of the farm field, reducing the output of the field for the farmer.	2

Discussion and Conclusion

Civil engineers must "include principles of sustainability in design," according to the ASCE [7]. ABET requires engineering graduates to have "an ability to apply engineering design to produce solutions that meet specific needs with consideration of public health, safety, and welfare as well as global, cultural, social, environmental and economic factors [11]." To meet those requirements, a real-world sustainable design project is an effective approach because it can reflect challenges and experiences students may face as professionals. Students used criteria to consider the social, economic, and environmental impacts of their designs which helped them to understand the importance of sustainability within their designs. The interactions between the students and the stakeholders provide the opportunity for students to develop design solutions that can benefit both the community and the student. The interactions encourage students to communicate effectively and become socially aware of the environmental impact of their

designs, which can better prepare them for the global challenges they may face after their graduations. Based on the course evaluation at the end of the semester, students reflected that the project motivated them to explore new knowledge and helped them realize the importance and urgency of integrating sustainability into engineering design.

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