Sustainable Urban Stormwater Treatment by Constructed Wetlands at Swarthmore College

Senior Engineering Design Project Proposal

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Abstract

In 2001, Marc Jeuland, a Swarthmore College student, built a constructed wetland to treat stormwater as a senior design project in the Crum Woods below the Mullan Tennis Center drain (known technically as C40). The wetland was constructed to be experimental in nature, as it is designed to hold only a small percentage of the flow from C40. Consisting of two channels, the initial experiment involved planting one channel and leaving one barren to determine the effects of vegetation on pollutant removal. At that time, preliminary results were obtained for wetland performance in each trench under background flow conditions. Stormwater treatment results were not obtained.

It is the focus of this project to continue where Marc Jeuland left off. Improvements to the site have been and will continue to be made. For example, the problematic gravitational system for delivering water to the wetlands has been replaced with a pumping system. After a semester of work with the Engineering 063 course – Water Quality and Pollution Control – the wetland is up and running again after a five year hiatus. The primary objective of this project is to determine whether or not constructed wetlands are an appropriate technology for this site. In this process, my hope is to make the wetland as adaptable as possible for experimental purposes and maintain a level of sustainability for research convenience and minimization of negative environmental impact.

Introduction

This proposal is divided into six sections: Technical Discussion, Project Plan, Critical Path, Realistic Constraints, Project Qualifications and Project Costs. The project plan outlines the three areas of the project – Site Characterization and Improvement, Sampling System and Sampling and Testing. The tasks and objectives of each area are presented followed by a project analysis including a Gantt chart and PERT chart in figures 1 and 2 at the end. This is followed by the realistic constraints of the project and my personal qualifications. Finally, there is an estimation of project cost - $700 - $1300 which is comparable to the $1265 cost of initial construction of the wetland by Jeuland. This cost could be reduced through innovation and reuse of current equipment.

Technical Discussion

The benefits of using wetlands for improving water quality for waste and stormwater treatment have been well studied and documented. The constructed wetland is a highly desirable solution for these problems, as it mirrors natural ecosystems providing sustainability and aesthetic value. These systems are divided into free water surface (FWS) flow, where the water table is above ground, and subsurface flow (SF) where it is below ground. SF wetlands are typically considered in cold climates to prevent freezing of the wetland. The constructed wetland at Swarthmore College in its current state is a FWS flow. The wetland is built alongside a tributary to the Crum Creek that flows from C40. It is currently oriented in a way such that it is too low relative to the tributary to become a SF without allowing backflow into the channels of the wetland from the river. The tributary is dammed by debris downstream before it enters Crum Creek, so it is possible that if this were removed it could lower the tributary water level enough to allow the wetland to be operated as SF.

Research from the Swarthmore Environmental Lab has shown that this tributary has elevated nitrate loadings from groundwater that keeps the tributary active all year long. Storm events bring elevated levels of phosphorus, organics and total suspended solids (TSS). It is also suspected that heavy metals may be elevated in the water as it drains the SEPTA rail line as well as the very busy two-lane State Route 320. An oil leak on campus in the not too distant past is currently being treated. However, it is possible that non-volatile hydrocarbons from said leak could be present and elevated in the tributary. Constructed wetlands have been proven to be successful in removing these pollutants from water. Nitrogen and phosphorus removal vary seasonally, as plants take up nutrients in the growing season and release them in the dying season. Efficiency results are currently being generated at the wetland during this dying season, so comparisons will be able to be made when data is collected in the spring. Knight, et. al. surveyed 127 separate constructed wetland systems, both FWS and SF and found the average values for efficiency removal of pollutants summarized in Table 1. As these are wastewater removal efficiencies, one would expect these to be smaller for stormwater as it tends to be highly diluted.

Table 1. Average Removal Efficiencies from Knight, R.L., et. al. "Wetlands for Wastewater Treatment: Performance Database." 1993.

Pollutant	Average Removal Efficiency (%)
BOD	73
TSS	69
Nitrate – Nitrogen	44
Total Nitrogen	64
Total Phosphorus	55

The effect of the vegetation within the wetland on removal efficiency is of interest in the scientific community. It is known that about 90% of pollutant removal in a wetland is a result of microbe activity in soil and on vegetation. Only about 7 to 10% of pollutants are directly removed by the plants. However, the plants may have a more important role to play in pollutant removal than just 7 to 10%. It is known that the roots of vegetation release oxygen to microbes as well as enzymes that speed up the chemical reactions of decomposition and pollutant removal. The benefit of oxygen dissipation by roots is the facilitation of aerobic conditions which alternate with anaerobic conditions farther away from root zones. This combination of aerobic and anaerobic conditions is much more effective for nitrate removal by denitrification.

The context of the site as an urban stormwater BMP is important and results acquired from the site's performance could help to better inform the knowledge base on these types of Best Management Practices (BMPs). For instance, urban stormwater is characterized by a "first flush" effect in which there is an initial spike in pollutants from water picking up pollutants sitting on the surface of roads, buildings and ground. After the first flush, the water is generally less harmful and more suited to be discharged directly into streams. The operation of the wetland and study of conditions at the C40 drainage site could help to inform general BMP design for diverting the first flush for treatment while allowing less polluted water later in the storm to collect into larger drainage. If a first flush is confirmed and late stormwater is relatively harmless, BMP designs could become smaller and thus cheaper for municipalities to implement because they would not have to handle as large of flows.

The goal of the wetland study will ultimately be to determine if a constructed wetland is an appropriate BMP for this location. The project will investigate the various considerations involved in making this decision, like the first flush effect, vegetation and seasonal variances in performance. The results obtained from this project can hopefully inform not only the college, but the larger scientific community in general.

Project Plan

I see objectives in this project fitting into three categories/phases. They are not exactly phases because they do not, as a whole, require the completion of one to begin work on the next. In general, though, the Sampling and Testing portion of the project will likely require most of the other objectives to be completed in order to begin. Below is an outline of the many tasks needed to achieve the objectives in each category:

Site Characterization and Improvement

Monitoring of wetland conditions and operation

- Monitoring storm events and possible flooding of wetlands
- Clearing of debris downstream causing damming of the tributary
- Monitoring of vegetation and removal of invasives

Porosity determination of soil/gravel mixture

- Compare between each channel at different points to determine effects of uneven flooding at site
- Alter porosity of channels if desired
- Verify state of sand in bottom of channels

Characterize hydraulic detention time

- Use color, salt or other various tracers
- Compare between different pump flow rates
- Compare between various storm and normal conditions

Improve pumping system

- Create system for changing pump flow rates
- Create and monitor system for powering from batteries and charging batteries with solar panels

Create system for determining flow rates from C40

- Measure heights of flow at either of the two 2-pipe outflows

- Create Weir gate
- Investigate use of remote monitoring devices (www.onsetcomp.com)

Examine inflow and outflow ports
- Determine orientations for SF and FWS flows

Construction of a one-way gate at end of channels to prevent back flow
- Research one-way gates
- Design and construct outflow gates
- Integrate outflow gates with sampling system

Create GIS mapping of C40 drainage area and characterize land uses and associated water pollutants
- Delineate C40 subwatershed
- Overlay land use
- Identify hot spots for different pollution types

Sampling System

Solar panel setup to charge battery for sampler and pumps
- Characterize solar radiation at site
- Determine orientations and locations for panel to maximize power output
- Choose and purchase panel based on voltage requirements, materials and surface area
- Install solar energy system

Setup sampling device at outflow to measure individually from both streams simultaneously
- Investigate use of multiple SONDE devices or an alternative ISCO sampling device

Sampling and Testing

Further research into constructed wetlands studies

Measure efficiencies for removal of pollutants
- Measure BOD, COD, TSS, Nitrate and Phosphate at inflow and outflow in different seasons and under different storm and normal conditions
- More testing could include heavy metals from cars and trains, pesticides if used in area, hydrocarbons and others
- Measure Temperature, pH and other parameters to compare efficiencies across various water parameters

Characterize pollutant removal along the length of the channel
- Use the SONDE to track pollutant levels in the different quadrants to see pollutant removal v. time

Compare removal between control and planted channels

Characterize first flush effect at site
- Implement this knowledge into an appropriate stormwater treatment schedule for storm events
- Explore the possibilities of detention tanks to hold first flush water for treatment

Report findings

Project Phases

Phase 1: Site Characterization and Improvement

Objective: To determine the changes undergone at the site since its initial construction and to learn more about the site including: drainage load, flooding and drainage area.

Approach: Since the site was initially prepared in 2001, by Marc Jeuland, it has undergone much natural change. Large storms have repeatedly flooded the site altering the composition of the channels. New porosity tests should be run on the channels in order to calculate new characteristic measurements of the wetland. The hydraulic retention time should be recalculated and remeasured for this new soil composition and for different flow rates and weather conditions. Also, the site should be monitored during storm events to determine the extent of floods and the hampering of the wetland's efforts in pollutant removal. Earlier in the year, the E63 class replanted the experimental channel with round rush plants, so the health of these plants should be monitored to ensure their service to the experiment and wetland. Monitoring should include observations of biomass size and color upon site visits. It would be very useful for this project to create a system for determining flow rates out of C40, so that pollutant loading can be determined from sampling. Also, it would be helpful to relate rainfall with storm water flow and to determine at what point the site begins flooding. Markings could be made on either of the pairs of storm sewers before the wetland, or a Weir gate could be constructed but may be unnecessary or inappropriate for the location. Also, remote monitoring devices could be employed at the outfall to measure flow rates by depth and velocity sensors. Different outflow gates should be utilized with varying flow rates to achieve SF and FWS flows and allow comparisons between the two systems. The pumping system is currently battery-powered, which could be charged by photovoltaic cells much larger and more effective than those currently in place. Finally, I feel it would be beneficial to use GIS to delineate the subwatershed and characterize land uses and potential hot spots for pollutants entering the storm water stream. These efforts may be helpful in modeling urban storm water runoff and extrapolating results achieved here for other drainage areas.

Output: A highly functional and adaptive wetland and a more comprehensive look at its drainage area.

Phase 2: Sampling System

Objective: To create a system of sampling inflows and outflows to the wetland and recording environmental conditions that upholds principles of sustainability.

Approach: Currently the ISCO 6712 sampler is setup in a concrete shelter for sampling at the entrance of the wetlands. I would like this sampler and the pumps to be powered by a marine battery that is charged by solar photovoltaic cells. These cells could be mounted on the shelter or on a pole to be constructed at the site. The site should be surveyed with a pyranometer to characterize solar radiation intensity throughout shady and sunny days. This data can then be used to find the surface area and design required for a proper solar photovoltaic to power pump and sampler. The sampling system will also require a setup for sampling both outflows from the channels simultaneously. Currently, a shelter is in place to house another sampler, but this setup may not be capable of such simultaneous sampling. SONDE devices may be employed here or some combination of SONDE and ISCO samplers.

Output: A sustainable sampling system for measuring the efficiency of pollutant removal in the wetlands and the concurrent natural conditions.

Phase 3: Sampling and Testing

Objective: To run meaningful experiments and collect data on pollutant removal in the wetlands. To identify this as either an appropriate or inappropriate technology for storm water treatment in this setting. To identify improvements and constraints for these systems in storm water treatment.

Approach: Using research and personal curiosity, wetland experiments will be designed to employ the sampling system and Swarthmore Environmental Lab to learn more about the wetlands. As soon as the sampling system is ready for use, storm events will be monitored and samples tested so that plenty of data under different conditions will be available for analysis. This will include considerations of the vegetation, seasonal variances in performance, the first flush effect as well as other considerations that will undoubtedly arise. The extent of sampling and lab testing may require the hiring of a field and/or lab assistant.

Output: A solid understanding of wetland performance under various storm conditions and a determination of the appropriateness of this setup for storm water treatment at C40. It is my aim that results inform the college as well as the scientific community.

Critical Path

The two pages at the end show the project time schedule on two different mappings. Figure 1 is the Gantt Chart, showing the start and end times of projects, float and duration times. Figure 2 is a PERT Chart of the project showing the paths of the project. Several of the tasks, including some of the more important ones were given zero durations because they are ongoing tasks. Thus, the final end date is misleading and should be expected much later. These figures do give a good idea, though, of the tasks that will depend on each other and their float times. In the table below are the time requirements and descriptions of the tasks used to create these charts.

Table 2. Properties of project activities.

Activity	Needs	Feeds	Duration	Effort	Action
Site Characterization and Improvement					
1. Clear damming of tributary	-	4, 8, 9	1 day	2 hours	Use shovels and blades to clear excessive brush in tributary.
2. Determine level and extent of flooding	-	4, 8	Ongoing		Monitor ongoing rain events and determine if and when flooding of wetland occurs.
3. Study composition of channels	-	-	5 days	5 hours	Investigate soil conditions including porosity
4. Measure hydraulic detention times	1, 2, 6	-	Ongoing		Measure over all different system orientations.
5. Monitor health of wetland plants	-	-	Ongoing		Monitor color and size of plants, remove invasives.
6. Develop variable flow pumping system	-	8	1 week	10 hours	Create or purchase circuit to provide variable current to pumps.
7. Determine flow rates and background pollutant levels from C40 site, characterize first flush effect	-	-	Ongoing		Continually measure pollutants in background flow and use remote-sensing device or other method

					for determining flow rate.
8. Experiment with flows and outflow gates to achieve various FWS and SF conditions	1, 2, 6, 9	-	2 weeks	10 hours	Plug and unplug different levels of outflow gates and observe effects.
9. Adapt outflow gates for prevention of backflow and sampling use	1, 2	16	1 week	7 hours	Develop system for using SONDE or ISCO samplers to measure outflow parameters.
10. Create GIS mapping for C40 drainage area	-	-	2 weeks	15 hours	Use school GIS software as well as HEC-RAS, ArcHydro or others to delineate and characterize drainage area.
Sampling System					
11. Study solar radiation at site	-	12	1 week	5 hours	Use pyranometer to find optimum angle and location for solar panel.
12. Determine orientation and size of photovoltaic panels	11	13	4 days	10 hours	Calculate required loads and find appropriate panels.
13. Design solar electric system	12	14	1 week	15 hours	Design wiring and structure for panels with help of Professor McGarity and Grant Smith.
14. Purchase photovoltaics and materials	13	15	3 weeks	3 hours	Order panels and supplies.
15. Install solar electric system	14		5 days	15 hours	Get tools and advice from Grant Smith.
16. Determine instruments and orientation for sampling outflow and inflow	9		4 days	10 hours	Investigate current instruments and new instruments for sampling use in outflow and inflow.
Sampling and Testing					
17. Further research of constructed wetlands studies	-	19	Ongoing		Consult recent journals for studies on constructed wetlands.
18. Test pollutant removal and environmental conditions for storm and normal events	16	21	Ongoing		Sample, record and observe wetland performance

					under various conditions.
19. Design experiments	7, 8, 16	20	Ongoing		Replicate or improve on current research or own ideas.
20. Carry out experiments	19	21	Ongoing		Enact experiments in the wetland.
21. Analyze data	18, 20	22, 23	10 days	15 hours	Consolidate, analyze and plot data in spreadsheets.
22. Determine effectiveness of BMP for application at C40	21		4 days	6 hours	Ruminate on results and develop arguments and explanations.
23. Prepare report	21, 22	-	5 days	30 hours	Draft report early for editing to inform final. report.

Realistic Constraints

The constraints associated with this project are expected to be time and cost. There are a wide variety of tasks and objectives that have been included and that could later be included to create a highly functional, adaptable and sustainable constructed wetland. The determination of the technology as appropriate or inappropriate for such an application is the prime objective of the project, and thus most time and resources should be applied to this end. Of secondary importance are adaptability of the wetland and sustainability. These are the aspects of the project that are likely to require the most innovation as well as incur the most costs. Sustainability and adaptability in this project are found mainly in the objectives of creating a solar electric powered sampling and pumping system, applying variable voltage to the pumps to control flow, and designing outflows that are adaptable and integrated for sampling. The costs for these secondary projects will depend on what is currently available on campus, what can be designed and built, and what must be purchased.

Project Qualifications

I have the academic and hands-on experience to complete this project. My academic resume consists of engineering, environmental engineering and natural science courses especially focused in water quality, including: Water Quality and Pollution Control, Toxic Water Pollution Analysis, Thermofluid Mechanics, Experimentation for Engineering Design, Solar Energy Systems, Ecological Engineering and Sustainable Development, General Chemistry and Ecology.

My practical experience includes summer research with Professor Arthur McGarity on stormwater modeling in an urban landscape. I have been involved with this research for almost two years now. In this time, I have learned how to analyze subwatersheds and predict pollutant loadings, use the SONDE, ISCO autosampler and laboratory methods to analyze Nitrate, Phosphate, TSS, BOD, heavy metals and several other pollutants. As these laboratory methods can be time consuming, and large amounts of experimental data are vital to this project, I may consider hiring a laboratory assistant for the latter stages of this project.

Project Cost

Solar panel	If cannot be acquired from on campus	$400
Solar panel mounting and wiring		$20-$100
Voltage regulator (http://www.kbt-dc-supplies.com/kits.php)		$30
Remote monitoring device (onsetcomp.com)	DC voltage or water level (more expensive)	$65-$500
New outflow gates	Need design	$40
Laboratory reagents		$50
Laboratory assistant	Student helper (2 – 5 hours / week, $8 hrs / week, 6 weeks)	$100-$150
Total		$700-$1300

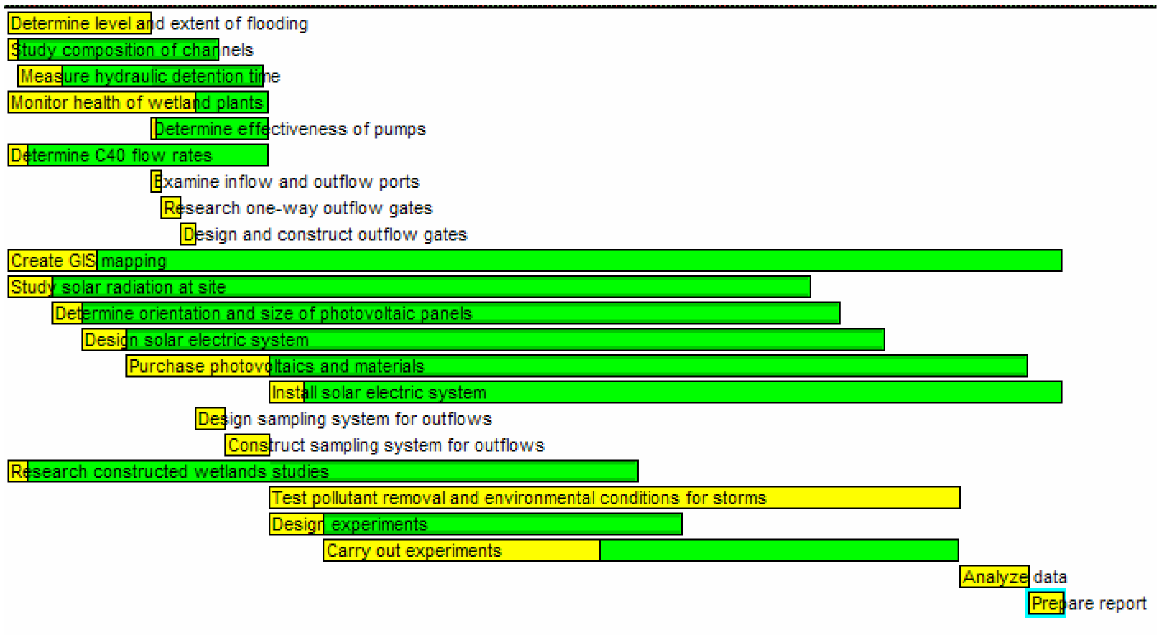

Figure 1. Gantt chart created with PlanBee shareware.

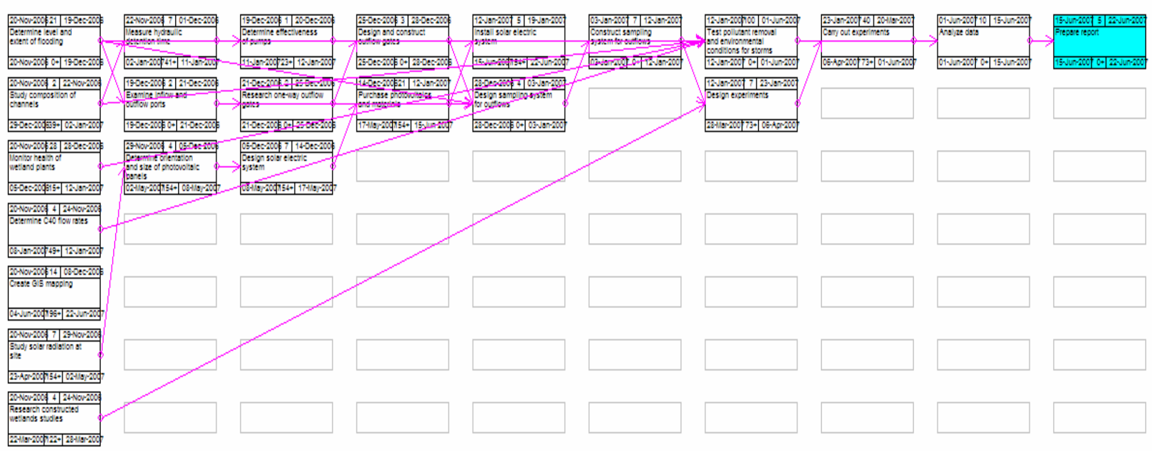

Figure 2. PERT chart created with PlanBee shareware.