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Providing Students with Hands-on Experiences through the Construction of a Treatment Wetland

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Abstract

Because of their natural water treatment capabilities, wetlands have been constructed for onsite treatment of stormwater and wastewater. As municipalities work to reduce the impacts of poor stormwater quality and potential combined sewer overflows on receiving water bodies, constructing treatment wetlands is a growing practice. Treatment wetlands provide a sustainable approach of onsite stormwater and wastewater treatment by improving the quality of stormwater runoff that enters receiving water bodies and by reducing loads on centralized treatment plants. To provide students with a hands-on experience of applying this treatment technique, two undergraduate students, under the direction of their advising professor, constructed a treatment wetland in the Cook Laboratory on the Rose-Hulman Institute of Technology (RHIT) campus. After researching constructed treatment wetlands and identifying our design requirements, we developed design alternatives and analyzed the alternatives with a decision matrix to develop the final design specifications. The final design included six separate basins in two parallel lines. The initial basins in each line were designed as sediment traps with sands as the primary component of the soil media. For the second basin, one line had a subsurface wetland and the other had a free water surface wetland. The final basins in each line were designed as finishing basins with a slightly higher clay content to promote phosphorus removal.

The primary objective of the constructed wetland is to test its capabilities to remove nutrients, suspended solids, and organic material from stormwater and/or wastewater. To test the removal efficiency of the treatment wetland system, we collected a stormwater sample from campus and pumped it through the wetland. Water samples were then collected at the outlet of each subbasin to investigate removal of nutrients, suspended solids, and organic material at each stage through the wetland system. Beyond the initial construction and testing, the main goal of having a functioning wetland system is to utilize the treatment wetland for laboratory experiments in RHIT's Environmental Engineering Lab course, as well as for future student research projects and potential demonstrations in other courses at RHIT. This will provide students with an active learning experience by performing tests of treatment capabilities on a real constructed wetland.

Introduction

Natural wetland systems perform important functions within an ecosystem, such as improving quality of water that flows through them, allowing absorption of rainwater for flood storage, cycling of nutrients, and providing wildlife habitat[1]. With a focus on improving water quality, constructed wetlands can be designed as stormwater and wastewater treatment systems by using natural processes of vegetation, soils, and microorganisms[2]. As it flows over land, stormwater picks up various nonpoint source pollutants, such as fertilizers, pesticides, sediment, oils, and greases, and carries these pollutants to receiving water bodies. In practice, constructed wetlands manage stormwater onsite by reducing the volume of surface runoff and improving the quality of runoff to receiving water bodies. Constructed wetlands have also been used to manage wastewater (both greywater and blackwater) onsite. In addition to being a technically feasible approach to treating wastewater, constructed wetlands are a cost-effective technique when compared to the cost of constructing traditional wastewater treatment facilities. Constructed wetlands also have lower operation and maintenance costs when compared to the energy use of centralized wastewater treatment facilities.

Currently in the Civil Engineering (CE) curriculum at RHIT, this technique is briefly discussed in Environmental Engineering and Water Resources Engineering courses without in-depth design or practical application of utilizing this treatment technique as a design solution. As we continue to stress the importance of sustainable design, an onsite treatment wetland would provide a non-conventional approach to stormwater management and wastewater treatment that is becoming more relevant in practice. Just as other learning institutions have wetland treatment systems from which students attain hands-on, experiential knowledge of the functionality of these systems[3,4], we want to provide students at RHIT with a similar opportunity.

For a summer research project, two undergraduate students at RHIT researched, designed, and constructed a treatment wetland in the Cook Laboratory for Bioscience Research on the RHIT campus. The summer research experience was funded through an grant program within the institute, where the students received a summer stipend for ten weeks of work on this project. As described herein, the students successfully met the following learning objectives:

1. conduct research on constructed treatment wetlands,
2. develop multiple solutions to an engineering project and determine the merits and deficiencies of each solution,
3. recommend the most appropriate solution based on developed criteria,
4. explain and document the solution in writing, and
5. construct the final recommended design under the supervision of the advisor.

Design Requirements

The goal of the constructed wetland is to filter water to remove nutrients, suspended solids, and organic material. The wetland should also be physically and visually accessible to students during the school year for course activities and potential research experiences. The wetland was required to fit on a 12 ft by 5 ft table inside the greenhouse at RHIT. The table also had a weight limit of 15 pounds per square foot. The plants used in the wetland should not be invasive or attract bugs that could affect other plants in the greenhouse. A budget of $2000 was given for the materials of the constructed wetland, including basin structure, basin media, plants, pipes, and pump.

Project Approach

The first step of the project was to research information on constructed wetlands and become familiar with the biogeochemical processes that occur. The student took a trip to the constructed wetland near RHIT campus to document types of native plants and soil. The students began to develop different design alternatives that would make the wetland efficient at removing nutrients and suspended solids, as well as serve as a teaching tool. After selecting the final design, the students estimated the costs of each material to make sure they stayed under budget. The weight of the material was calculated to make sure the table could support the basins. The table could only support 900 pounds, and the materials surpassed that weight. To resolve this issue, the amount of materials was reduced and the table was strengthened with extra leg supports to hold 1800 pounds.

Design Alternatives Considered

<u>Design 1</u>

Design 1 (Figure 1) is made of two different treatment lines. One running in a subsurface flow and the other in a free water surface wetland. Each line has three stages. The first and third stage for both lines are very similar. They contain soil and gravel to filter the effluent. The second stage in each line differed between subsurface and free water surface. For the subsurface flow line, the second stage is composed of a layer of soil where there will be a mix of wetland plants. These wetland plants could include sedges, rushes, and grasses. For the free water surface design the second stage is composed with a fine layer of soil on the tank bottom and filled up with water. There are floating and emergent plants in the tank. The water flows from one stage to another using gravity by positioning each following stage below the previous stage. In addition, between the stages are tubes for collecting samples after each stage to test the water quality. This design provides an advantage of having interchangeable stages, so the process could be altered by creating different treatment lines to analyze various configurations. For a teaching tool to be used in class, this design of several stages instead of one big tank enables the system to be transported more easily.

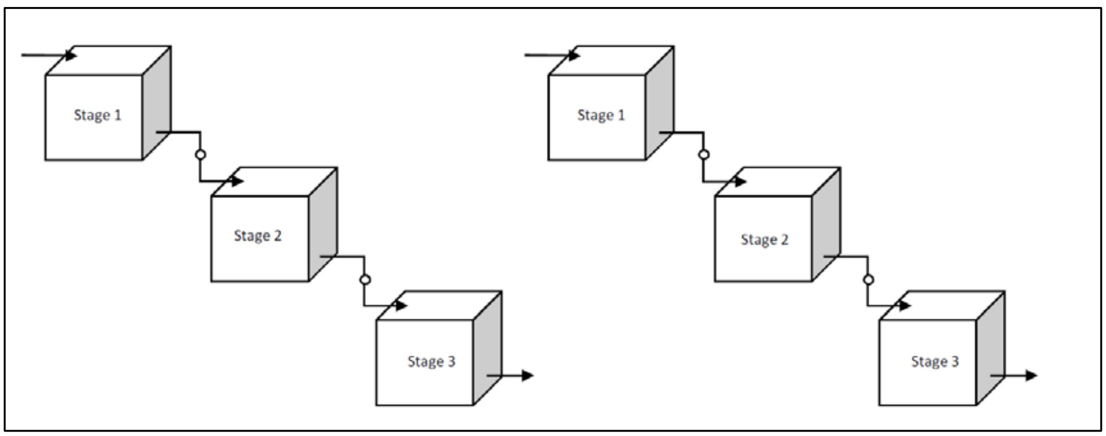

Figure 1: Design 1 featuring two parallel systems with three stages in each

<u>Design 2</u>

This design would also simulate both subsurface flow and free water surface wetland treatment conditions in parallel (Figure 2). Each container contains an environment in small scale. Using transparent material for the lateral wall will make it possible to show the students the layers that compose the soil and the subaquatic plants. The advantage of this design is the possibility to create a continuous environment to simulate a natural wetland. The subsurface flow container will be filled with gravel, soil, and plants. The water will flow through the soil layer from the surface on one edge until reaching the outlet on the opposite side. In the free water surface wetland, there will be a relatively small soil layer on the bottom that slopes as it approaches the smaller faces of the container, forming a bank. The plants will be positioned on the banks and in the edges of the basin. The aquatic plants are submerged and emergent.

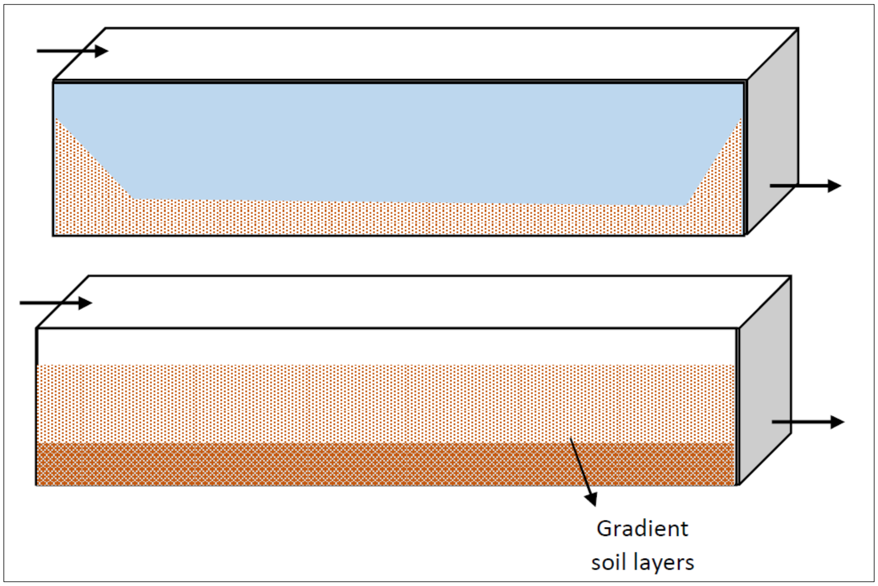

Figure 2: Design 2 featuring two parallel systems

Design 3

Design 3 is composed of one large basin (Figure 3). Using just one basin we would be able to use a bigger variety of plants due to the larger space. For learning purposes this design is beneficial since it is a single scale model of a wetland, but it would have to either be a free water surface or a subsurface flow wetland, due to the large space occupied by the basin that impedes the use of both treatment methods at the same time. After choosing either free water surface or subsurface flow, the design will follow the same description of one of the basins for the Design 2.

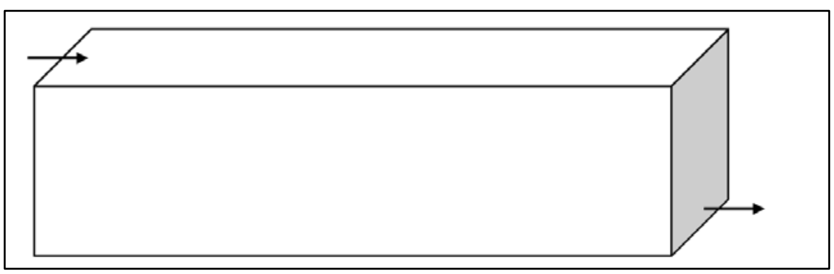
Figure 3: Design 3 featuring a single basin

Evaluating Design Alternatives

The following criteria (Table 1) were used to evaluate the design alternatives. Removal efficiency, constructability, and maintenance were equally weighted as being more important than appearance and interchangeability. Removal efficiency, constructability, and maintenance (each 25%) are necessary factors for the function of the wetland when compared to appearance and interchangeability (each 12.5%) that are aesthetic aspects of the wetland.

Table 1: Description of evaluation criteria

Criteria	Weight	Description
Removal Efficiency	25%	Treatability of stormwater
Constructability	25%	Level of difficulty in building basins and availability of materials
Maintenance	25%	Ease of replacing media in basins for routine cleaning/flushing
Appearance	12.5%	Look of plants in wetland and viewable by students
Interchangeability	12.5%	Flexibility in design to experiment with free water and subsurface

In evaluating each design, a rating of 3 represents a design that meets the criteria well, while a rating of 1 represents a design that poorly meets the criteria. The decision matrix (Table 2) shows that Design 1 is the design that best meets the criteria.

Table 2: Decision Matrix

Criteria	Weight	Design 1	Design 2	Design 3
Removal Efficiency	25%	3	3	1
Constructability	25%	1	2	3
Maintenance	25%	3	2	1
Appearance	12.5%	3	2	1
Interchangeability	12.5%	3	3	1
Total	100%	**2.5**	**2.4**	**1.5**

In determining the ratings for how well each design met each criterion, removal efficiency of Designs 1 and 2 were rated better than Design 3 because the free water surface and subsurface basins could be connected together with Designs 1 and 2. Since the water would flow through two systems, more suspended solids and nutrients could be removed which would increase the efficiency of the wetland. Constructability was rated low for Design 1 it would require more work to construct six basins, whereas Design 2 has two basins and Design 3 has only 1 basin. Maintenance was rated highest for Design 1 because the media in the separate basins could be more easily emptied and refilled when needed. Appearance was rated highest for Design 1 because it physically separates the system into three parts so students have more viewing area. Interchangeability was rated highest for Designs 1 and 2 because the two parallel systems can be operated separately or connecting together to compare removal efficiency between independent systems or connected systems.

Final Design Summary

<u>Design Objectives</u>

The purpose of this project is to build a constructed wetland and test water quality measures in stream water as it flows through the system. The design consists of two parallel systems that will independently treat the water. Each system is composed of three basins connected by a series of pipes to move the water from one basin to the next. The basins are emulating a natural environment with soil and plants similar to the natural wetlands. The two systems are placed on a table which has an area and weight limitation that is considered in the design process. Since each line in the system is composed of three separated basins, the basins and connections need to be arranged to create a gradient for water to flow from one basin to the next. The water should be evenly distributed through the width of the basin to provide a homogeneous flow. To obtain this homogeneous distribution the water passes through a perforated pipe. After the water enters in the collection pipe it will flow through a valve that can control the flow to the next basin. At the last basin, the water is to be collected in a reservoir. There are valves at the outlets of each basin to allow for samples to be collected for analysis at each stage through the system.

System Configuration

The final design consists of two independent systems that can be cross-connected to create a new system. Clear acrylic sheets were used to construct the basins, so that students could see through the basins to view the filter media and emergent plants. The clear material makes a better visible teaching tool. The material used to connect the basins and allow water flow include two-inch diameter PVC pipes, plastic pipe fittings, valves, and vinyl tubing. Each system is organized into three basins (Figures 4 and 5). The first and last basins are similar in size at approximately 2 ft wide by 2 ft long and 1 ft high. The second basin is 2 ft wide by 5 ft long and 1 ft high. The acrylic sheets were cut to dimension, assembled using acrylic cement, and sealed with aquarium safe silicone. The largest basin was also reinforced with screws holding together the edges of each acrylic sheet to provide added structural support. Because leaks were prevalent at the screw locations of the larger basins, the smaller basins were only assembled with acrylic cement to minimize leaks and use of extra silicone to seal the leaks.

The water enters into the system from the top of the first basin and flows horizontally through the basin. The water is collected by a drainpipe at the downstream end of the basin. The water collected passes through a valve and flows into the second basin through a perforated, horizontal pipe that evenly distributes the water into the third basin. The basins are stair-stepped so that the water uses gravity to flow through the basins. The first basin is placed on an aluminum rack that is 1 ft tall, and the second basin is on a rack that is 0.5 ft tall.

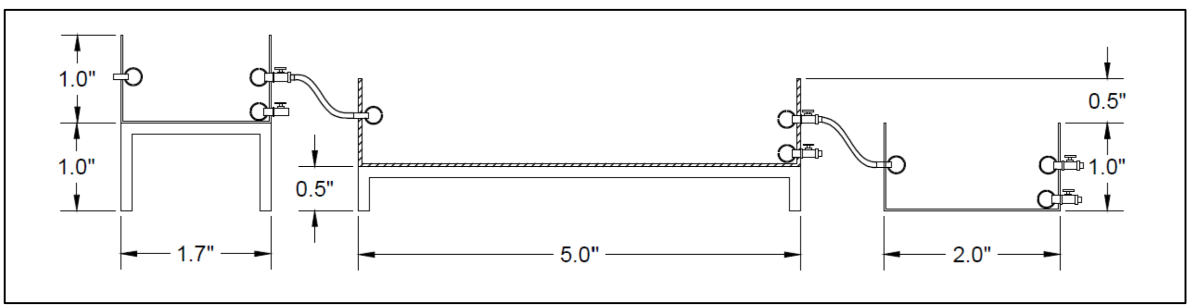

Figure 4: Profile view of one wetland system

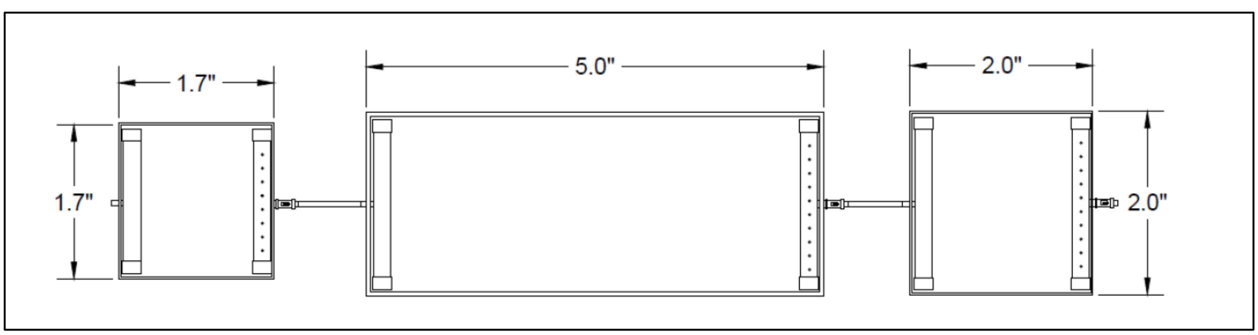

Figure 5: Top view of one wetland system

Substrate Selection

The first basin in each system is designed to filter out suspended solids. The purpose of the second basin in each system is nutrient uptake via either free water surface flow or subsurface flow. The third basin of each system further filters the smaller solids from the water and a higher clay content is meant to absorb phosphorus. Gravel was placed along the base of each basin and around the perforated distribution and collection pipes for structural stability. The soil composition included a local topsoil that consisted of 50% sandy loam, 25% peat, and 25% composted yard waste. Sand was added to the topsoil at varying amounts for each basin, with the highest percentage of sand in the first filtration basin in each system and lower amounts of sand in the second and third basins to promote longer retention times and allow for nutrient uptake by the plants.

Plant Selection

Plants were purchased from a greenhouse that supplies native Indiana wetland plants. Sedges and grasses were selected for the subsurface flow basins (Figures 6 and 8), while knotweed, pondweed, and water lilies were selected for the free water surface basin (Figures 7 and 9). Due to an approximate six inch rooting depth in the subsurface basins, plants were chosen that were less than 3 ft tall and spaced approximately 18 inches apart.

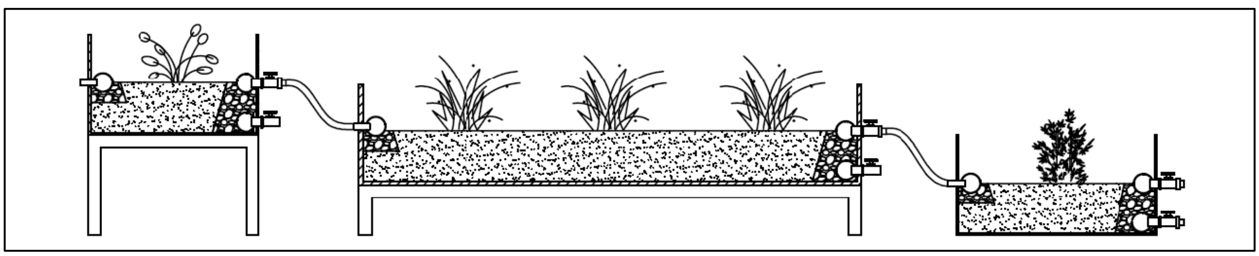

Figure 6: Profile view of subsurface flow wetland system

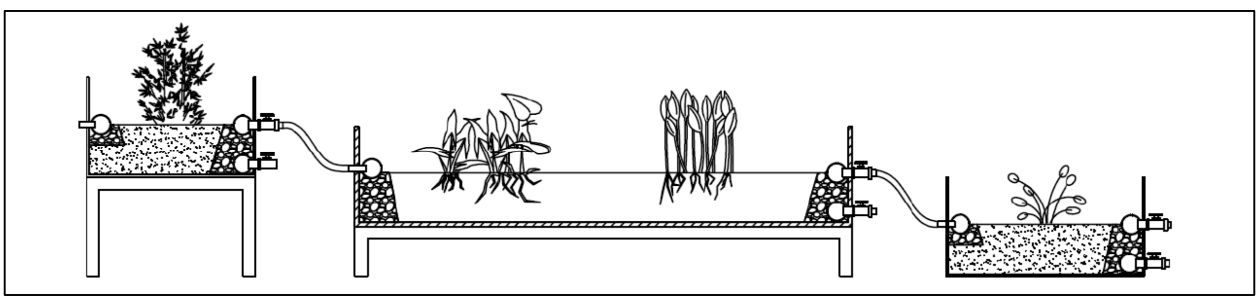

Figure 7: Profile view of free water surface wetland system

Figure 8: Final subsurface system

Figure 9: Final free water surface system

Challenges Faced

Within three months after construction was complete, the acrylic cement on the four smaller basins failed under the lateral soil and water loads. The corners of the basins broke apart along the edges. The basins were emptied and cleaned. Corner braces were added to each basin to provide additional structural support.

Future Plans

The design and construction of the treatment wetland was just an initial step of an ongoing project to utilize the wetland in the Environmental Engineering Laboratory course, as well as providing the opportunity for further summer research projects for undergraduate students.

The Environmental Engineering Laboratory course is structured such that students conduct a different lab experiment each week of the term. Current and past experiments include coagulation and flocculation simulation, measurement of filter clean bed head loss, collection of water quality characteristics in a nearby stream to assess nonpoint source pollution impacts, determination of BOD_5 from stream water samples, and measurement of oxygen uptake rates from a sample mixture of return activated sludge and wastewater collected from the city's wastewater treatment plant. The course is required for students in the CE Department during their junior year (approx. 40 students per year). Two sections of the course meet separately for lab so that approximately 20 students are meeting for lab in each section. At the beginning of the term, students are assigned to lab groups of 4-5 students per group. Labs are conducted over three class periods. Students are required to submit scientific experimental reports, including purpose, background, hypothesis, methods, results, and conclusions, for each weekly laboratory experience. Upon successful completion of this course, students should be able to:

1. prepare for laboratory experiences with appropriate steps of pre-experiment planning
2. conduct bench-scale unit operations in environmental engineering
3. utilize common environmental analytical instrumentation
4. perform data analysis and report writing

For incorporation into the course, an experiment will be conducted whereby stormwater will be collected as it drains into a nearby stream. This stormwater will be pumped through the wetland with sub-samples collected at each of the basin outlets to measure water quality throughout the system over time. Water samples will be analyzed for total suspended solids, ammonia, nitrate, and phosphate. This will be conducted as one of the weekly laboratory experiences by the entire class. Each team will collect sub-samples from one or two of the basin outlets and share their water quality data with the entire lab section for analysis and interpretation of results to assess removal efficiency of suspended solids and nutrients. Depending on the quantity of the original stream water sample and the retention times of each basin, students may need to return to continue sample collection until the entire volume of sample water reaches the outlet. In this case, students will alternate among their team members to ensure that sample collection is complete. Students will analyze the water samples onsite for total suspended solids, ammonia, nitrate, and phosphate.

To assess learning, student course evaluations will be used to evaluate the lab course with additional questions included to assess this particular experience of how well the treatment wetland experiment improved their understanding of how a treatment wetland functions. Pre- and post-lab survey questions of treatment wetland operations will be posed to students to determine how well the practical learning experience improved their knowledge and understanding of the topic.

In addition to utilization in the course, the existence of the treatment wetland provides opportunities for summer research projects for students. The versatility of the wetland design allows for changes in the configuration to compare removal efficiencies of the parallel lines in the system, as well as develop a new system that connects the free water surface and subsurface basins in series for comparison with each running each line individually. Further experimentation of varying pumping rates, changing basin media composition, and collecting raw sample water from various sources (including stormwater and greywater) provide potential for long-term use of the treatment wetland as an on-going living laboratory.

Bibliography

1. United States Environmental Protection Agency (USEPA). 2004. *Constructed Treatment Wetlands*. EPA 843-F-03-013. Office of Water. August 2004.
2. Campbell, C. S., and M. Ogden. 1999. *Constructed Wetlands in the Sustainable Landscape*. Jon Wiley & Sons, Inc. New York, NY.
3. Living Machine. 2012a. *Evergreen - Western Wayne County Schools*. http://www.livingmachines.com/Services/Case-Studies.aspx (accessed March 2014).
4. Living Machine. 2012b. *Furman University, Greenville, SC*. http://www.livingmachines.com/Portfolio/Schools-Universities/Furman-University.aspx (accessed March 2014).