A Stormwater Constructed Wetland Utilizing Renewable and Recyclable Materials and Native Wetland Plants

University of Hawaii, Manoa
Natural Resources and Environmental Management
Molecular Biology and Bioengineering

June 2008

Purpose, Objectives, and Scope

Our objectives for Phase II are to build the constructed wetland designed during Phase I, test its treatment performance, and develop an on-site educational display and web-based educational information and materials to raise awareness of the need for stormwater treatment and the possibilities of innovative and sustainable solutions such as constructed wetlands to improve water quality in urbanized watersheds.

Data, Findings, Outputs/Outcomes

In order to determine the type of storm flow the constructed wetland would need to capture and treat, we needed to model the drainage basin area as an urban watershed. That required information on the basin area, topography, rainfall patterns, and estimated runoff. We installed a HOBO weather station (Onset Computer Corp., Bourne, MA) within the storm water drainage area that measured air temperature, relative humidity, solar radiation, wind speed, and rainfall. Measurements were taken every 30 minutes and included the average temperature, relative humidity, and solar radiation; the average and maximum wind speed; and cumulative rainfall. Measurements were taken from October 26, 2007 through March 18, 2008. A summary of daily air temperature and rainfall is listed in Figure 1. Air temperatures varied from 15-30º C. The total rainfall was ~800 mm over the 5-month period, which is approx. half of the total annual rainfall for this area (Giambelluca et al. 1986). The maximum rainfall intensity was ~30 mm/hr, and the maximum daily rainfall was 110 mm. By way of comparison, the expected 10-year rainfall intensity is ~60 mm/hour. Over 90% of total rainfall events were < 3 mm (Fig. 2), but the total rainfall received was distributed across the various rainfall intensities (Fig. 3)

Figure 1. Summary of Daily Air Temperature and Rainfall.

Temperature in ºC on the left axis; rainfall in mm on the right axis. Maximum temperature in red; minimum temperature in green; rainfall in blue.

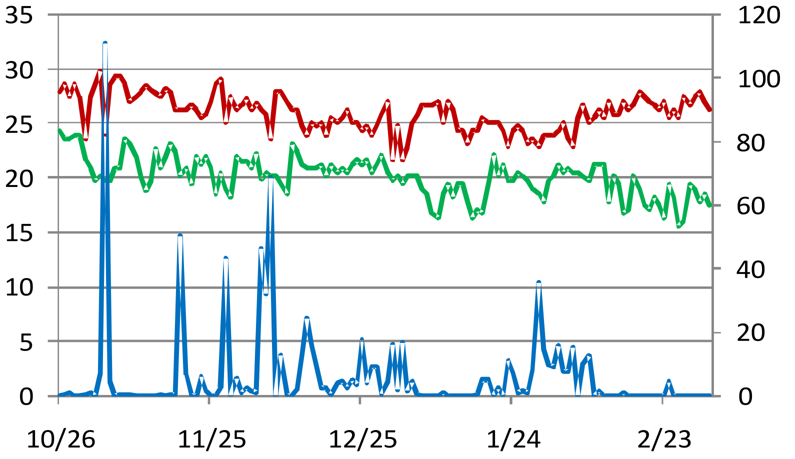


Figure 2. Frequency Distribution of Rainfall Events (#) by Rainfall Intensity (mm/hour)

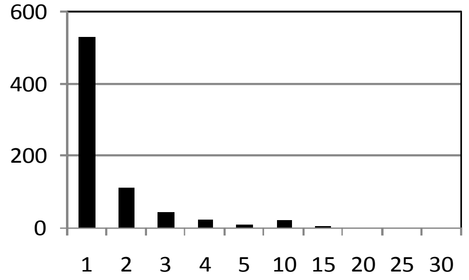
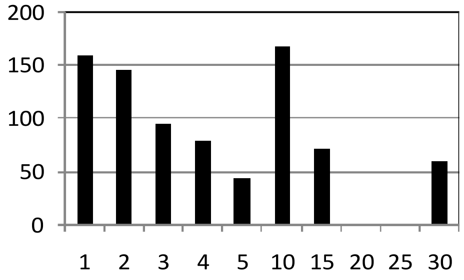
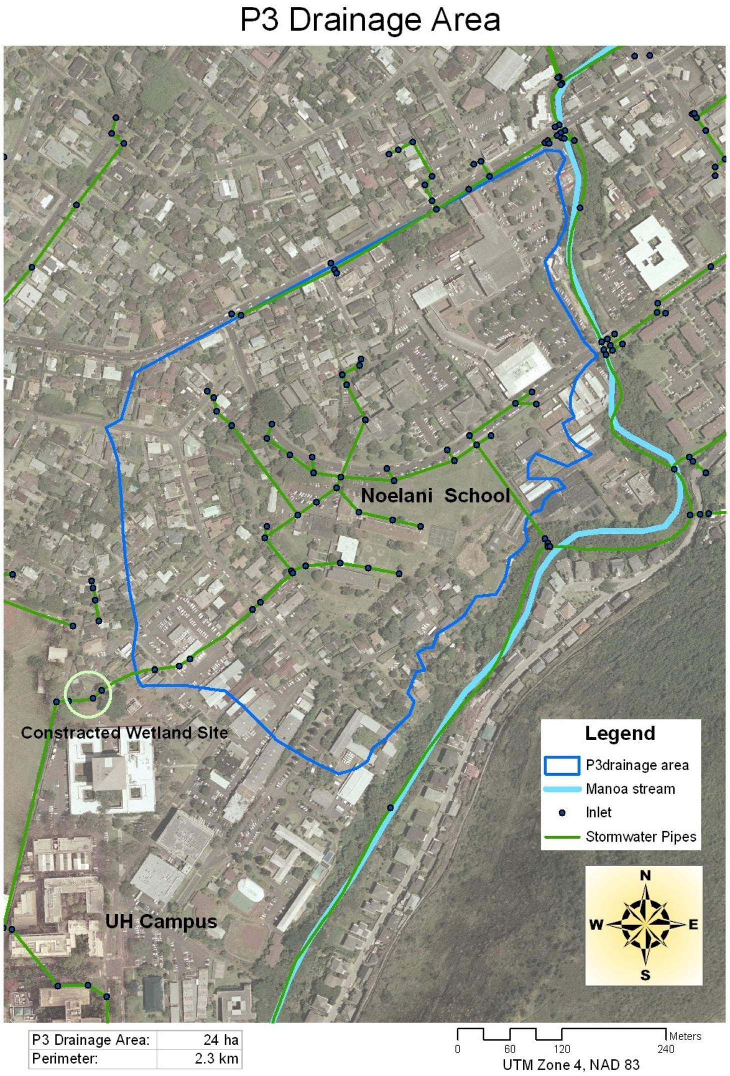


Figure 3. Frequency Distribution of Rainfall Amount (mm) by Rainfall Intensity



We used a high resolution topographic GIS data layer and a city map of the storm drain network to determine the size and expected water discharge from the storm drain (Fig. 4). The drainage basin area was estimated at approx. 275,000 m^2. This includes an elementary school, a shopping center, a public library, greenhouse facilities, homes, and several roads and parking lots. Based on the degree of urbanization in the drainage basin, we estimated approx. 80% of rainfall would run off into the storm drain network. For a 10-mm/hr rainfall event, that would result in approx. 1800 m^3 of water moving through the storm drain. This would result in a peak flow of 0.5 m^3/sec. Given the small area available for the constructed wetland, this presents a challenge for capturing and treating storm water during the peak portion of a rainfall event.

Figure 4. Drainage Area and Storm Drain Network. The blue line delineates the total drainage area, based on topography breaks. The green lines delineate the storm drain network. Dots represent storm drain inlets. The white circle identifies the location of the proposed constructed wetland. Below the white circle, stormwater flows aboveground in a series of canals and concretized stream channels into the Ala Wai Canal.

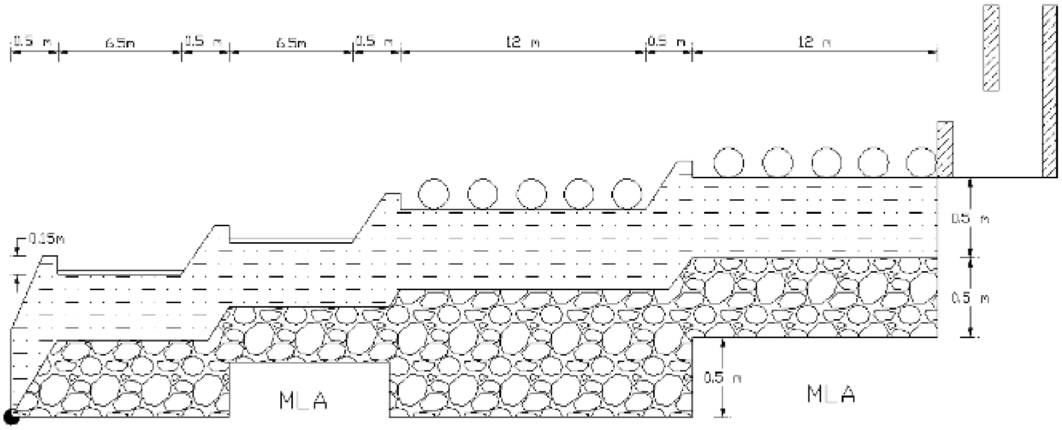

P3 Drainage Area

We also collected water samples from the storm drain outflow point in order to determine the expected water quality entering the wetland. The major pollutants of concern are suspended solids and bacteria levels. We found relatively low levels of nutrients and heavy metals that are below the limits set for recreational water bodies in Hawaii.

This information was used to design a multiple-cell subsurface flow constructed wetland in order to capture and treat the storm water from the drain pipe. The storm drain empties into a concrete detention basin that is 4.9 by x 3.6 x 0.5 m in size. This detention basin slows down the first flush of water, allows gravel and coarse particulate matter to settle out, and directs the flow of water through two 10 x 50 cm weirs. Afterwards, the water moves through an open gravel and soil ditch within an area approx. 40 m long by 5 m wide. The water then enters another storm drain underneath a road that empties into a concrete canal that transports the water toward Manoa Stream. The major constraint to the wetland is this narrow 40 x 5 m area. The total in elevation is 1.5 m from the storm drain outflow (wetland inlet) to the wetland outlet.

After discussion of our options and constraints, we decided to design a wetland with 4 subsurface flow cells that is designed to temporarily capture storm water (Fig. 5). This design is intended to encourage storm water to infiltrate through a soil-mulch mixture into a gravel substrate underneath and ultimately through the subsoil underlying the system. Flow rates that exceed the infiltration capacity will spill into adjoining wetland cells, moving through the system until it exits the wetland system.

Figure 3. Constructed Wetland Design.



Each wetland cell will be 5 m wide, the maximum available. The length of the first two wetland cells will be 12.5 m, and the final two cells will be 6.5 m each. At the outlet of each cell will be a 15-cm high barrier of rip-rap (stone and gravel) to allow for temporary ponding of water on the wetland surface to encourage further infiltration and ensure sheet flow of water over the surface when flow rates exceed infiltration capacity. This rip-rap barrier will also disperse the energy of the water when it overtops the wetland cell and moves into the adjacent cell. This will reduce the risk of scouring and erosion of the wetland cells during high-flow events.

The top layer of the wetland will be a mixture of soil excavated from the ditch and landscaping mulch generated from routine maintenance of landscaping on campus. The soil is classified as a Makiki stony clay loam with a published infiltration rate of 15-60 mm/hr (Web Soil Survey 2008). The landscaping mulch is a free and renewable organic substrate that can maintain maximum water infiltration rates and reduce the risk of erosion of the soil. The woody mulch also will serve as a carbon-rich organic source that can increase microbial immobilization of nutrients in storm water. It can be replaced periodically as needed. In the first two wetland cells, we will use coconut coir logs to help slow water flow and filter out suspended solids. Logs will be place across the width of the cells at 2-m intervals, with a 2-m buffer between the inlet and outlet points. These logs are themselves a renewable organic substrate that also provides a high-carbon substrate for microbial immobilization of nutrients in stormwater.

We will plant native wetland sedges in all four wetland cells. The native bulrush, *Schoenoplectus tabernaemontani*, will be planted in the coconut coir logs to provide a living anchor for the logs. Two additional native sedges, X and Y, will be propagated from sprigs using a hydromulch application technique (Hydroseed Hawaii, Honolulu, HI), that ensures rapid establishment and reduces erosion risk during the establishment period. Plants are available from a local native plant nursery (Hui Ku Maoli Ola, Kaneohe, HI). All of the wetland species are tolerant of saturated soil conditions and resprout readily after dry periods. This reduces the requirement for irrigation and replanting.

Underlying the soil-mulch mixture will be a 50-cm base of gravel. This material will be recycled graded concrete available from a local supplier (Grace Pacific, Kapolei, HI). This material not only prevents the need for mining of quarry rock, it is less expensive, as well. The porosity of this material was estimated as 50% of total volume based on tests in a 15-L container. Water infiltrating the gravel substrate should move quickly to the subsoil underneath, which is also a Makiki stony clay loam. We anticipate the infiltration rate of this material to be near the lower end of the published value (15 mm/hr), since it will be compacted by the overlying gravel and soil-mulch mixture.

A bypass system will be incorporated in the design to prevent flooding of the system. Pipes will be installed into the side of the gravel substrate just beneath the soil-mulch mixture and empty into a concrete ditch running parallel to the wetland cells. This ditch will connect to the storm drain at the outlet of the wetland system.

Based on the weather information, drainage basin, and wetland design, we used a watershed model in order to determine stormwater runoff and wetland treatment capacity. Data from December of 2007, the wettest month of the measurement period, was used to simulate wetland performance. The maximum infiltration capacity of the wetland was estimated at ~215 m^3/day. Under conditions of rainy weather over several days, the capacity drops to ~95 m^3/day, meaning that most water flows through the system. The residence time of stormwater in the system ranged from 1-5 days, with an average time of ~1.5 days under continuously rainy conditions. The general recommended retention time is 2 days for effective treatment of wastewater. Although this is a significant limitation of our wetland design, the small available area for constructing our wetland is a general problem for highly urbanized areas. In a larger watershed context, the construction of a series of wetlands along a stream or stormwater system would allow for multiple opportunities to infiltrate and treat stormwater, decreasing storm flow and improving water quality overall. This could be especially effective for capturing the first flush of stormwater runoff after a dry period, which likely contains the majority of suspended sediments, heavy metals, nutrients, and other pollutants.

Discussion, Conclusions, Recommendations

Our goal for the first phase was to design a constructed wetland to capture and treat urban stormwater runoff in the Manoa-Palolo watershed in order to improve water quality in the Ala Wai Canal, an EPA 303(d) listed impaired stream. We used on-site weather data and GIS-based delineation of the drainage area and storm pipe network to determine the stormwater runoff in the area. Based on collection of stormwater samples, we found that the first flush of storm water has a high pH and electrical conductivity, meaning that this water is likely impaired for total suspended solids and nutrients. Additional analyses will reveal the degree of heavy metal contamination, as well. Using this information, we designed a multi-cell subsurface flow wetland that utilizes renewable and recyclable materials and native wetland plants to enhance its performance and sustainability. Based on a watershed model, we determined that this wetland has the capacity to provide reasonable treatment of stormwater, but the constraints of the available area for the wetland will limit the effectiveness during rainy periods or intense storm events.

The design as outlined above represents an optimal approach given the constraints of a highly urbanized watershed. This is likely to be a common challenge in other urbanized areas. However, it also represents a potentially effective strategy to treat urban stormwater runoff that takes up a minimum of space, is relatively inexpensive, utilizes renewable and recyclable materials, and provides lost habitat for native wetland species. Our vision is to use this design as a model for other community groups to replicate throughout the watershed. Some constructed wetlands in urban watersheds can be much larger than the one outlined here. In Manoa and related valleys on Oahu, there remain large parks and green space that could be partially converted back to wetland habitat, greatly expanding the potential size and effectiveness of treatment wetlands. Instead of engineering concretized solutions to stormwater runoff that only exacerbates downstream flooding and water quality problems, a series of constructed wetlands would reduce stormwater runoff, enhance aquifer recharge, improve water quality, and engage communities in the management of their natural resources more directly, raising awareness of interrelated environmental issues and stimulating further innovation and collaboration to develop sustainable solutions.