Research Plan

Challenge Definition

Management of water resources is one of the biggest environmental challenges of the 21st century. Access to reliable, clean drinking water is becoming a primary natural resource concern in growing urban areas around the world (UN WWDP 2006). In Hawaii, rain-fed groundwater provides most of the island of Oahu's drinking water for its more than 900,000 residents and tourists, and most of the agricultural and industrial water, as well. The sustainable use of this water resource requires balancing extraction with recharge. With an increasing population and subsequent demands for clean drinking water, voluntary restrictions on lawn irrigation and other non-essential uses are becoming common during dry periods. Population growth has forced the City and County of Honolulu to begin planning for construction of a $40 million desalination plant to supplement this supply (Board of Water Supply 2004).

Discharge and treatment of storm and waste water are also important considerations for human and environmental health, especially when coupled with inadequate clean drinking water supplies (UN WWDP 2006). Storm water is increasingly being recognized as a significant potential non-point pollution source (US EPA 2002). In urban areas, impervious surfaces prevent infiltration of rain water. This runoff is channeled into storm drains and either treated in wastewater treatment plants or discharged directly into natural water bodies. Treating storm water puts a tremendous strain on treatment facilities during large storm events. It also represents a lost opportunity to recharge groundwater aquifers.

On the island of Oahu, untreated storm and waste water are regularly discharged directly into the Pacific Ocean during heavy rainfall events, seriously polluting marine ecosystems and causing beach closures (Leone 2006a). During a 40-day rainy period in early 2006, the increased pressure caused the rupture of a large municipal waste water pipe near the tourist area of Waikiki. The City and County of Honolulu diverted 48 million gallons of untreated storm and waste water into the Ala Wai Canal, disrupting recreational and tourist activities and tarnishing the image of Hawaii as a paradise for vacationers (Leone 2006b). Even under normal conditions, the Ala Wai Canal is included on the EPA 303(d) list of impaired streams on Oahu, with specific concerns for nutrients, pathogens, turbidity, lead, suspended solids, organochlorines and pesticides (Hawaii Dept of Health 2004). The canal is a receiving area for storm water coming mainly from the surrounding urban and rural areas of Manoa and Palolo Valleys, including the campus of the University of Hawaii, Manoa. Total maximum daily load standards have been established only for nutrients (Koch et al. 2004). A report by the Ala Wai Watershed Water Quality Improvement Project (AWWWQIP) lists storm drain contaminants, especially those originating from vehicles, as non-point source pollutants of concern (AWWWQIP Steering Committee 1998).

Relationship of Challenge to Sustainability

One of the innovative strategies that can address these concerns is the use of constructed wetlands to capture and treat storm water. Such systems have been successfully used in Europe for over 10 years (Magmedov et al. 1996). In most cases, these wetlands significantly reduce non-point source pollutants, including total suspended solids, nitrogen (N) and phosphorus (P), heavy metals, and pathogens (Magmedov et al. 1996, Kao et al. 2001, Kohler et al. 2004). Because flow rates and pollutant concentrations vary temporally, treatment efficiency may also vary considerably (Revitt et al. 2004, Scholes et al. 2004). However, treatment efficiency seems to be highest during storm periods, when pollutant concentrations are at their greatest (Scholes et al. 2004). The US Environmental Protection Agency (EPA) lists constructed wetlands as a viable treatment option for runoff and erosion from new urban or residential developments (US EPA 2005). In general, constructed wetlands are useful in urban areas wherever there is a concentration of runoff or the desire to protect sensitive areas such as natural wetlands (e.g. Kohler et al. 2004).

The efficient removal of pollutants provides opportunities to reuse treated storm water for irrigation purposes. This has several benefits. First, it reduces the demand from primary drinking water sources, such as aquifers or surface reservoirs. Second, it allows urban runoff to be reapplied to permeable surfaces, where it can be naturally filtered and decontaminated as it percolates back into underground aquifers. Third, it reduces the flow of storm water in storm drains, reducing pressures on treatment facilities and the discharge of pollutants into natural water bodies. An example of this is found at the Purdue University golf course in West Lafayette, IN. A constructed wetland is being used to treat runoff from the golf course and the surrounding urban area. The quality of the treated water is sufficient to be reused for irrigation of the golf course or discharged directly into the adjacent Celery Bog wetland when irrigation is not needed (Kohler et al. 2004). The state of Hawaii has encouraged use of recycled water by establishing water quality standards for various intended uses (Wastewater Systems Administrative Rules 2004). This has led to an increasing use of recycled wastewater for irrigation of parks, golf courses, agricultural areas, and university campuses (HWEA 2006). The challenge remains to capture, treat, and reuse storm water, as well.

Costs associated with most constructed wetlands are small compared to wastewater treatment plants. Constructed wetlands used to treat homeowner wastewater can generally be installed for $10,000-20,000 (US EPA 2005). Because constructed wetlands to treat storm water are based on the same design, costs should be similar. They require little infrastructural support and no large-scale planning, as opposed to centralized wastewater treatment facilities. They are also essentially modular in nature: additional parallel or serial cells can be added where space permits to handle larger flows or new sources of storm or waste water. Finally, the simple design requires little maintenance over its expected operational lifetime other than harvesting of vegetation and cleaning biofilm accumulation in inflow and outflow pipes (Magmedov et al. 1996).

Social benefits of constructed wetlands include enhanced community relations through favorable land use policy, enhanced aesthetic appeal, and the creation of recreational and educational opportunities. Constructed wetlands can also be suitable habitat for native wetland plants and associated fauna. The large constructed wetlands associated with the Purdue University golf course were initially vegetated with 10,800 plants representing 18 different species (Kohler et al. 2004). A small constructed wetland on the island of Hawaii successfully used a native reed, *Cyperus laevigatus*, to reduce nutrient, total suspended solids, and fecal coliform loads in wastewater (Van Dyke 2001). In an urban setting such as a university campus, a constructed wetland can be landscaped as an educational and attractive green space, providing service-learning and teaching opportunities for campus and surrounding community members. This provides a visible link between the community and the resources it utilizes, raising awareness of larger sustainability issues.

Objectives and Hypotheses

Major Objective. Design a constructed wetland to reduce non-point source pollutants in urban storm water sufficient to recycle the water for on-campus landscape irrigation.

Phase I Objectives and Hypotheses

O1. Measure the normal range of storm water discharge based on rainfall events.

H1. Discharge will be highly variable temporally with rapid increases during rainfall events.

O2. Analyze the concentration and speciation of non-point source pollutants from an urban storm water pipe on the University of Hawaii-Manoa campus, including total suspended solids and their particle size distribution; inorganic and organic N and P; biological oxygen demand; and heavy metals during storm events.

H2. Pollutant levels and suspended solids will be highest early during storm events. Most nutrient and metal pollutants will be adsorbed onto fine particles.

O3. Choose constructed wetland design parameters based on storm water discharge rates and pollutant concentrations and speciation.

H3. A 2-stage constructed wetland will be optimal to retain and treat the highly variable flow rates and pollutant loads associated with urban storm water.

Approach

We have identified a suitable location on the University of Hawaii, Manoa campus for a constructed wetland to treat urban storm water. A 54-inch storm water pipe runs underneath the upper end of the Manoa campus. The storm pipe drains two major paved and graveled areas: the nearby Noelani Elementary School and the UH-Manoa Transportation Services vehicle lot (Fig 1, Appendix). The storm pipe is open at its lower end. Water exiting the pipe creates an erosional ditch in an unpaved area, then flows under a parking lot and into a concrete channelized ditch that eventually drains into the Ala Wai Canal. The unpaved area between the parking lot and the storm pipe outflow is of sufficient size for a constructed wetland. It is also adjacent to an outdoor nursery used by the UH-Manoa Landscape Department to propagate plants for campus landscape projects. We propose to capture and treat storm water flowing out of this storm pipe and reuse it as irrigation water for the nursery or other nearby landscaped areas on campus.

For the first phase of this project, we will engage in data-gathering and consultation with professionals and community members in order to 1) define the critical design features of the constructed wetland; 2) develop an effective plan for treating and reusing the storm water; 3) create a list of potential native wetland plants to treat the storm water and landscape the constructed wetland; and 4) create educational opportunities for university and k-12 students in the community and throughout the island.

The critical design features of a constructed wetland can vary; however, there are basically two main types in common use. The first type is a free water surface pond, also known as a vertical constructed wetland. Here, water is detained in a tank where solids and associated nutrient or heavy metal pollutants settle out of the water column. Floating aquatic plants may also sequester nutrients and metals. The second type is a subsurface flow wetland, also known as a horizontal constructed wetland. Here, water percolates horizontally through a coarse substrate, usually sand and gravel, that provides surface area for microbial attachment or rooting of emergent aquatic plants. This maximizes biological sequestration of nutrients and metals and allows for microbial transformation of organic pollutants, reducing toxic hydrocarbons and overall biological oxygen demand (BOD). A horizontal flow wetland can have a free water surface, especially during times of greater water inputs during storm events (Scholes et al. 2004).

Both types perform reasonably well at reducing pollutants, but vegetated and horizontal flow wetlands are better at trapping fine sediments (Bavor et al. 2001). Best results are generally achieved with a two-stage system in which water initially flows into a vertical flow cell to allow for settling of coarse sediments and then is discharged into a vegetated horizontal flow cell to allow for trapping of fine sediments and biological sequestration and decontamination of nutrient, metals, and organic matter (Magmedov et al. 1996, Kao et al. 2001).

Principle Design Components to be Considered

Three design considerations are critical in the development of a constructed wetland, including hydrologic effectiveness, hydraulic effectiveness, and water quality treatment processes, as well as aesthetics (Table 1). First, the hydrologic effectiveness is the long-term average percentage of the storm water runoff subject to treatment. This design criterion should be based on the catchment hydrology, characteristics of the specific pollutants, and site constraints. An attempt to balance the wetland size and detention period will increase the hydrologic effectiveness. Both the flow and detention time are defined by the local-scale design issues such as shape, bathymetry, type and locations or inlet and outlet structures, and botanical layout. Second, the hydraulic effectiveness is determined by how well the water moves through the wetland. Two major components of good hydraulic effectiveness are uniform flow (plug flow) and available storage volume utilization. These factors allow all parcels of pollutants to experience similar detention periods and reduce short-circuiting, recirculation, and dead zones. Lastly, water quality treatment processes are designed specifically to the target pollutants.

A minimum of two cells is typically required. The first cell is an open water inlet for course sediments and hydraulic pretreatment (vertical wetland cell). The second cell is for removal of fine sediments and soluble particles (horizontal wetland cell). The botanical design is also an essential aspect of water quality treatment processes, which includes macrophyte layout, species selection and establishment, and ongoing maintenance. In addition to these three major design components, the educational and aesthetic value of the wetland is important. Wetlands provide a great service to the community not only protecting against flooding and improving water quality, but also by educating youth and the community in environmental issues and providing a positive aesthetic externality.

<u>Evaluation Methods and Measurable Results</u>

The important factors to considered in the process of designing the constructed wetland include annual precipitation, seasonal distribution and storm-event characteristics of rainfall, average temperatures within Manoa Valley, evapotranspiration, and land uses of the watershed. Annual rainfall and temperature data will be obtained from the Natural Resource Conservation Service. Weather data specific to the drainage area will be collected by a solar-powered, wireless weather station that records air temperature, relative humidity, barometric pressure, wind speed and direction, and rainfall. The weather station will be placed on the Noelani Elementary School campus and data recorded in a partnership with the school’s faculty and students. The drainage basin characteristics will be determined from a spatially explicit database and on-the-ground measurements collected and analyzed in partnership with students in the NREM senior capstone course, NREM 494: Environmental Problem Solving.

Table 1. Constructed Wetland Design Considerations

3 Principle design components:

I. Hydrologic effectiveness – capture and retention of runoff
II. Hydraulic efficiency – distribution of inflow evenly across the wetland
III. Water quality treatment processes – physical, chemical, and biological processes through wetland flora and fauna and in prescribed retention time

	Independent variables	Dependent variables	Design variables
Hydrologic effectiveness	Rainfall generation (sequence and magnitude of flows)	sedimentation, rate of filtration and adsorption of solids and dissolved pollutants	Storage volume, pre-treatment components, # cells
Hydraulic efficiency		nuisances (mosquitoes), evapotranspiration	Retention time, structure of each cell (dimensions), # cells
Water Quality treatment processes	Climate, pollutants (monitoring of inputs and outputs)	Maintenance of system (disposal of waste,	Substrate (type, depth, retention time, # cells, vegetation, microorganisms (nutrients, temperature, pH, aerobic or anaerobic, and energy source), order of treatment

Possible pollutants	Primary capture/treatment
Solids	settling, substrate filtration
heavy metals	adsorption/precipitation to substrate and plants
hydrocarbons	adsorption/microbial degradation
nutrients	adsorption, uptake by microbes, plants

This data will be utilized to create a hydrologic budget, estimating storm water flow into the constructed wetland. Climate data and expected storm water flow will be used as a guide in choosing the type of flow system, the targeted retention time, and which native wetland plant species are best suited for use within the system.

The constructed wetland design also depends on the types and concentrations of pollutants in the storm water and by the area available for the project. This may vary depending on past and current land uses of the contributing watershed, the nature and intensity of storm events, and time of concentration of runoff within the watershed. Team members will sample storm water near the beginning and end of individual storm flow events to test for the presence of a variety of suspected pollutants. Total suspended solids will be determined based on dry mass of evaporated samples. The pipette method will be used to determine particle size distribution of sediments (Gee and Bauder 1986). Biological oxygen demand will be determined using a standard 5-day incubation (APHA 1995). Nutrients and heavy metals will be analyzed in partnership with the laboratory of Dr. Eric DeCarlo in the Department of Oceanography at UH-Manoa. Water samples will be filtered to separate dissolved from particulate-associated species. Filtered water samples will be analyzed directly for dissolved inorganic species using an ion chromatograph. Dissolved inorganic N will be analyzed using a colorimetric analysis on an auto-analyzer. Filtered water samples will be digested in alkaline persulfate for analysis of total N and P (Cabrera and Beare 1993). Organic N and P will be calculated as the difference between digested and undigested samples. Sediment-associated nutrients will be determined by persulfate digestion and then analysis for total N and P.

Samples will be analyzed in triplicate to obtain an estimate of analytical precision. Results will be compared to analytical standards in order to estimate analytical accuracy. The findings of pollutant concentrations will be compared to Hawaii Department of Health human health based screening levels to determine the need for treatment (Water Quality Standards Administrative Rules 2004). Constructed wetland design parameters will be customized based on these findings to reduce pollutants to state standards for irrigation reuse (Wastewater Systems Administrative Rules 2004).

Possible Problems/Issues to Consider

The constructed wetlands should be able to operate under various conditions. During times of low flow, maintenance of the constructed wetland may be required. For example, depending on species type, plants may wilt and affect the water quality treatment. As a result of low flows, standing water could cause other nuisances, such as an increase in mosquitoes. In addition, with high nutrient loads, algae growth may become problematic. Furthermore, removal and disposal of collected sediment will need to be properly handled in accordance with State and Federal regulations. We will discuss these maintenance issues with companies and government agencies with experience in designing and maintaining constructed wetlands. We will partner with Derek Chow, Project Manager of the US Army Corps of Engineers led Ala Wai Canal Project.

Finally, alteration of storm water flows and reuse of treated water may require specific permits from the City and County of Honolulu or the State of Hawaii. We will partner with the Ala Wai Canal Project to explore which permits will be necessary. This information will be used to approach the City and County Board of Water Supply and the State Department of Health to discuss permitting requirements.

Innovation and Technical Merit

Most constructed wetlands are created with only a single source of wastewater in mind. However, their simple design and modular nature makes them easily adapted for multiple water sources. An advantage of the location chosen for this particular project is its proximity to other sources of wastewater. Wastewater from the nearby UH-Manoa Energy House, a living facility constructed to illustrate alternative energy and sustainability design principles, could be treated in additional wetland cells. The John A. Burns Biomedical Building is also adjacent to the drain pipe. The building relies on a chilled water cooling system to provide air-conditioning. This water could be filtered through an additional wetland cell, used to dilute other sources of wastewater to meet recycled water quality standards or to maintain water levels in the storm water wetland cells during dry periods. During the Phase I development process, we will design the storm water constructed wetland as the first stage of a planned multi-stage and multi-purpose on-site wastewater treatment and recycling system.

Finally, this project will provide an opportunity to test the feasibility and acceptability of native Hawaiian plants in constructed wetlands. Recent studies by co-PI Traci Sylva have focused on assessing the ability of plants native and unique to Hawaii to remediate waste streams. These studies have focused on phytoremediation of sewage waste, contaminated soils, and impacted surface waters. Some of these native plants have shown unique abilities as compared to other more well-studied plants in the literature. During Phase I, we will search the literature and talk with knowledgeable native plant growers and restoration experts to develop a list of potentially suitable species for this project. Roxanne Adams, manager of the UH-Manoa Landscape Department, will be a key partner in this effort.

Demonstration Strategy

Because the constructed wetland will be placed on the UH-Manoa campus, it will be easy to hold on-site tours during the implementation phase. As a part of the landscaping plan, we will provide permanent educational displays for self-directed tours. The specific purpose of the wetland and its integration into the university's strategic plan for promoting sustainability (UH Manoa Strategic Plan 2004) will be highlighted. Future plans and the larger vision for treatment and reuse of multiple sources of wastewater will be included.

Educational Integration

Implementation of a constructed wetland on the university campus provides both undergraduate and graduate students with independent research opportunities as well as providing instructors an educational tool to communicate environmental, hydrological, and sustainability issues. Research ideas include investigations into appropriate exotic or native plant species, harvesting rates of plants, nutrient cycling, and analysis of contaminants. We will partner specifically with Carol Ferguson, the instructor for NREM 494: Environmental Problem Solving. This is a senior capstone course that uses a case study approach to teach environmental problem solving concepts and skills. Other departments, such as Civil Engineering or Molecular Bioscience and Bioengineering could also use this project as an active learning tool.

Education will also be expanded to local k-12 schools, where the project will serve as an example of place-based learning. This will enhance classroom lectures, encourage environmental stewardship, and build connection with the community. Use of the constructed wetland as an educational tool provides an interdisciplinary and interactive environment where cooperative learning is encouraged and literacy, research, technology, character development, and service-learning can be incorporated. There are three k-12 schools that are adjacent to the proposed site: St. Francis High School, Noelani Elementary School, and Mid-Pacific Institute. We will partner with John Cusick, director of the UH Environmental Center and Nancy Ali, staff member in the Bishop Museum Science Education Department, to develop appropriate on-site educational activities as well as k-12 curricular materials.

Project Schedule

First 3 Months

- Determine information needs for development of design criteria in partnership with Army Corps of Engineers
- Purchase weather stations and install at Noelani School
  Begin collecting weather data
- Begin gathering geospatial data on drainage area in partnership with NREM 494 students
- Monitor storm flow and begin collecting storm water samples
- Train student team members in sample analysis protocols in partnership with Eric DeCarlo laboratory in UH Department of Oceanography
- Begin developing ideas for educational displays and curricular materials in partnership with UH Environmental Center and Bishop Museum Science Educational Department
- Research native wetland plants with potential for use in the constructed wetland cells in partnership with the UH Landscape Department
- Discuss possible permitting requirements and needs with the Ala Wai Canal Project

First 6 Months

- Analyze weather data and make presentation to Noelani School students
- Analyze geospatial data and make presentations to all three k-12 partner schools in partnership with NREM 494 instructor and students
- Collect additional storm water samples and begin analyzing water samples for pollutants in partnership with UH Department of Oceanography
- Present plans for educational displays and curricular materials to partnering k-12 schools and the instructor for NREM 494 for feedback
- Interview native plant growers and restoration experts to create a refined the list of potential native plants
- Approach city and state regulatory agencies about permit needs and requirements

First 9 Months

- Apply weather, geospatial, and water analysis data to design criteria and develop a draft of the constructed wetland design in partnership with the US Army Corps of Engineers
- Finalize educational and demonstration plans and work actively with NREM 494 students to use the constructed wetland sustainability challenge as a case study for the course

- Decide on list of native plants to be tested in the constructed wetland
- Develop integrated display and report for the EPA P3 Sustainability Contest Symposium
- Finalize decisions about permit needs and develop a plan to collect necessary data

First Year

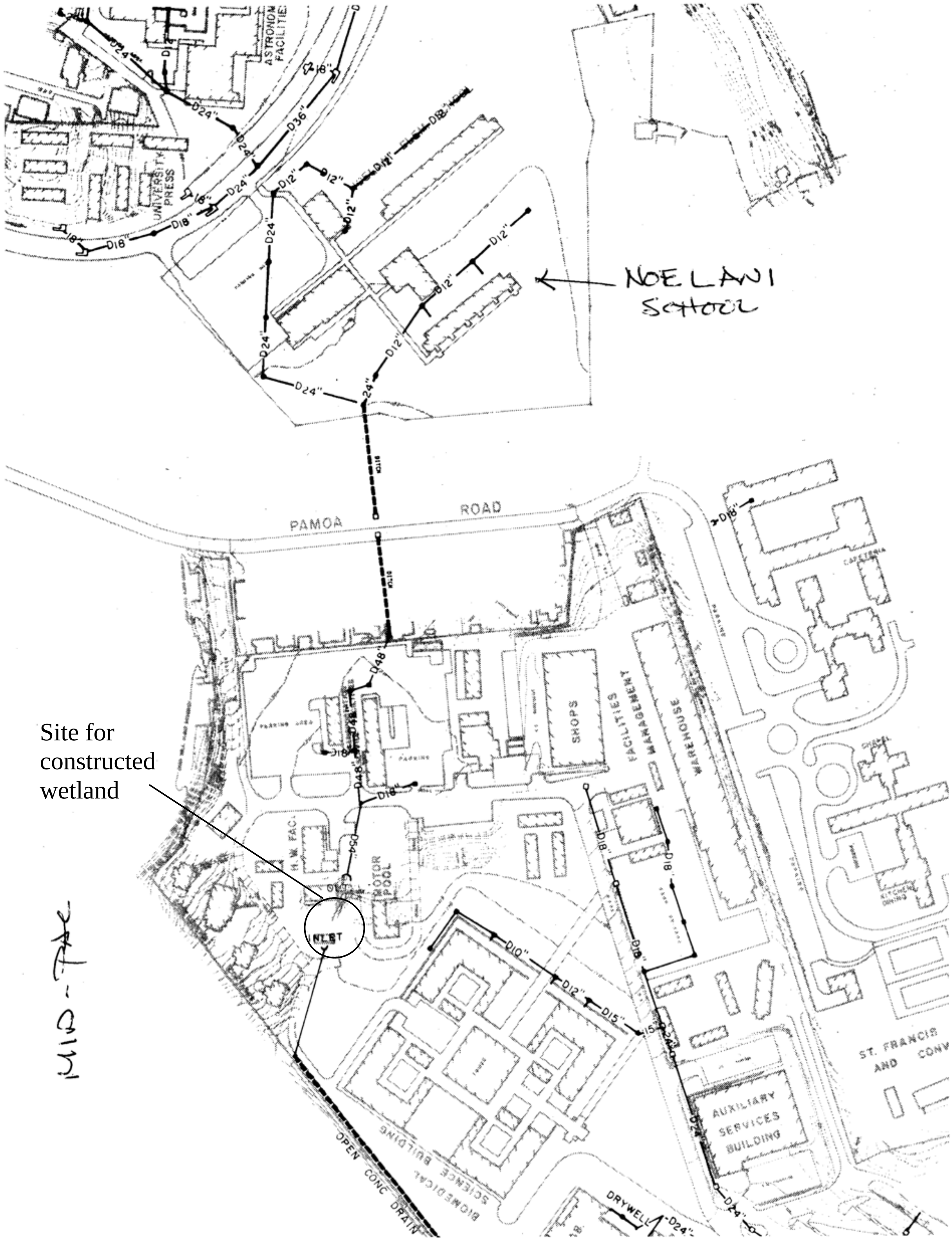
- Refine constructed wetland design based on symposium review and comments
- Use refined design and symposium display and report as the basis for soliciting additional funding to support the implementation phase of the project
- Fill out permit applications and submit to appropriate regulatory agencies

<u>Partnerships</u>

1. Derek Chow, US Army Corps of Engineers and Director of Ala Wai Watershed Water Quality Improvement Project
   -consulting for data needs and design criteria
   -review of draft constructed wetland design
   -exploration of permit requirements
2. Rochelle Mahoe, Principal of Noelani School
   -installation of weather station and collection of weather data
   -feedback on demonstration strategy, educational displays, and curricular materials
3. John Cusick, UH Environmental Center and Nancy Ali, Bishop Museum Science Education Department
   -development of demonstration strategy, educational displays, and curricular materials
4. Eric DeCarlo, UH Department of Oceanography
   -train students on water quality testing protocols and test water samples for pollutants
5. Roxanne Adams, UH Landscape Department
   -develop list of wetland plants appropriate for water treatment on campus landscaping
   -provide contact information of native plant growers and restoration experts for refinement of wetland plants list
6. Carol Ferguson, Instructor for NREM 494
   -develop constructed wetland design as a case study for the course

Appendix

Figure 1. Schematic Drawing of Storm Pipe Drainage Area and Site for Constructed Wetland.



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