DESIGN OF RESEARCH FACILITIES FOR GRAYWATER TREATMENT USING WETLANDS

BY ANURITA

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ABSTRACT

The main objective of this study includes the preliminary design of a constructed wetland to treat the graywater coming out of the Atmospheric Science Building, Foothills Campus, Colorado State University, Fort Collins, Colorado and to establish a healthy and diverse ecosystem in the constructed wetland. The main source of graywater coming out of the building is from the wash basin sinks. The wetland size was determined to be 4.9m*1.6m*0.8m. The hydraulic retention time was 25 days at average flow and 16.67 days at peak flow. The facility was designed using the Aerial Loading Rate (ALR) method. The wetland includes a forebay and a micropool at the inlet and outlet respectively. There are three berms included in the wetland. First, at the inlet, the second at the center of the wetland body and the third along the micropool. Three v-shaped flow spreaders are included in the first and second berms to provide a uniform distribution of the flow throughout the wetland. There are two v-shaped flow collectors installed in the berm surrounding the micropool in order to collect the treated water. The vegetation in the wetland is emergent. The wetland outlet is a 90 degree V-notch weir installed in a concrete box. A stilling well is attached to the V-notch which records the head readings at any given point which in turn helps in determining the flow rates. The top of the concrete box is fixed with a trash rack. The treated graywater collected in the wetland outlet is directed to the main sewer by a bottom drain pipe. A Geo Synthetic Liner is incorporated at the bottom of the wetland in order to prevent infiltration of graywater into the water table. The wetland is designed only to treat graywater. The stormwater is diverted from the wetland. The stormwater that falls on the wetland body will only be treated. There are two sampling locations located at the inlet and the outlet structure of the wetland. A third sampling station can be located at the berm which is at the center of the wetland. The wetland has to be maintained regularly to ensure the environmental integrity, aesthetic enhancement and wildlife benefit for future generations. The constructed wetland has to be monitored regularly in order to identify any problems present and thereby improve the treatment facility. The parameters to be monitored and the frequency of monitoring have been laid out. The capital cost was estimated to be $176.00. But the actual cost will turn out to be much greater than this amount. However, the costs will be much lower when compared to those constructed wetlands that are larger.

THIS STUDY IS DEDICATED TO MY PARENTS AND MY BROTHER

ACKNOWLEDGEMENTS

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CHATER 1

INTRODUCTION

Extensive research work has been carried out on treatment of wastewaters in constructed wetlands. Constructed wetlands have proved to be a promising treatment facility in treating wastewaters originating from a variety of sources as well as the constructed wetlands work in both warm and cold climates. Constructed wetlands are low in cost and utilize low energy.

Graywater treatment using constructed wetlands has not been much emphasized. This project focuses on a complete preliminary design of a constructed wetland to treat graywater only. There is no pre- and post – treatment of the graywater involved. The graywater source is from the wash basin sinks in the Atmospheric Science Building, Colorado State University, Fort Collins, Colorado. This project can serve for future research to determine whether constructed wetlands are promising in the treatment of graywater.

OBJECTIVES

The main objectives of the project are:

1. To achieve the removal of pollutants of concern and pathogens from the graywater originating from the wash basin sinks in the Atmospheric Science Building, Colorado State University, Fort Collins, Colorado.

2. Establish a healthy and diverse ecosystem in the wetland.

3. To ensure compliance with federal, state and environmental laws which protect human health and environment.

4. Through monitoring the wetland by regular sampling and laboratory analysis effectiveness of the project can be determined.

CHAPTER 2

WETLAND AND GRAYWATER OVERVIEW

2.1 WETLANDS IN GENERAL

Wetland technology to treat wastewaters is being considered extensively. Wastewaters originating from different sources like urban runoff, municipal, agricultural, industrial, animal waste and acid mine drainage are being treated using wetlands as a natural way to uphold the deteriorating environmental conditions. Wetlands are natural water or wastewater purification systems that use low cost and low energy methods to improve water quality. They also require low operational attention.

A wetland is an ecosystem which is transitional between aquatic and terrestrial ecosystems. It is saturated by surface water or groundwater and is characterized by a prevalence of vegetation that is adapted for life in saturated soil conditions like swamps, bogs, fens, marshes, wet meadows, tidal wetlands, floodplains, ribbon (riparian) wetlands along stream channels and estuaries (http://www.epa.gov/glnpo/ecopage/docs/glossary.html). Wetlands are being used extensively to treat wastewater because of their three basic functions (Chan et al., 1981):

1. Physical entrapment of pollutants through sorption in the surface soils and organic litter.
2. Utilization and transformation of elements by microorganisms.
3. Low energy and low maintenance requirements to attain consistent treatment levels.

Constructed wetlands are manmade complex and integrated ecosystems used to treat wastewater. They are shallow systems usually with depth less than one meter. Constructed wetlands are designed to maximize the removal of pollutants in the wastewater. They utilize many mechanisms to achieve maximum pollutant removal like microbial breakdown of pollutants, plant uptake, retention, settling and adsorption. Constructed wetlands treat pollutants like solids, Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), nitrates, nitrites, phosphorous, microbes etc. Constructed wetlands can be of two types: free water surface wetland and a subsurface flow wetland. The plan and profile of a constructed wetland is shown in figure 1a and 1b respectively.

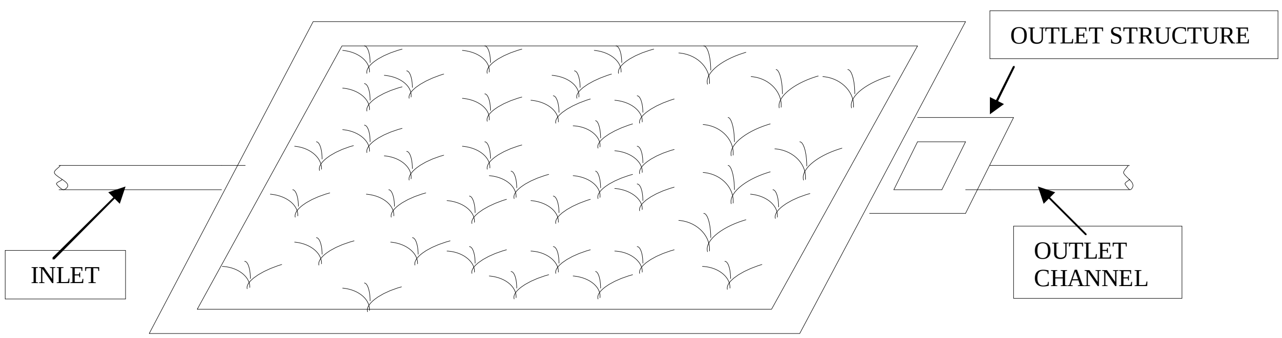
Wetlands provide many ancillary benefits. They provide reliable pollutant removal, long life, adaptability to a variety of developmental sites and habitat, food, and breeding areas to a variety of plant and animal species. They also provide educational and aesthetic values. Wetlands offer a number of important services to society and are crucial for sustaining and improving water quality. The refining processes observed in the natural wetlands are mimicked in constructed wetlands.

Wetlands help in flood and erosion control by functioning as natural sponges, storing water and releasing it slowly. This naturally occurring filtration process is so effective that many communities are looking for wetland protection and mitigation. Natural wetlands are getting dewatered because of land development practices which have resulted in larger quantities of pollutants entering the water bodies which in turn deplete the water quality.

FIGURE 1 A

FREE WATER SURFACE WETLAND

PLAN



PROFILE

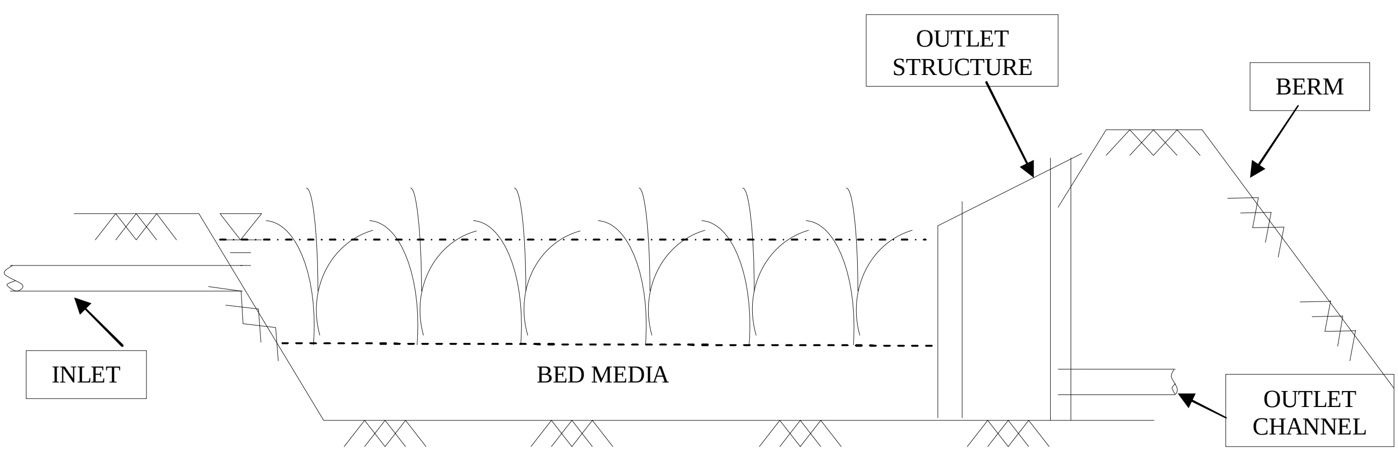
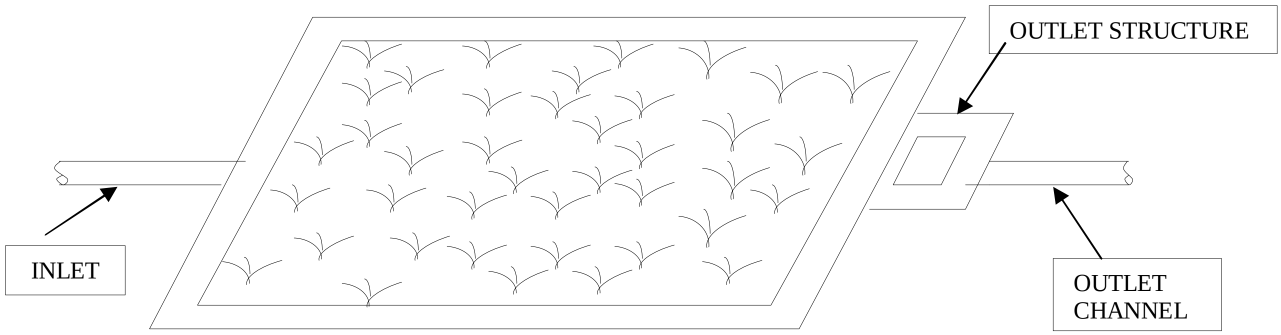


FIGURE 1B
SUB SURFACE FLOW WETLAND

PLAN



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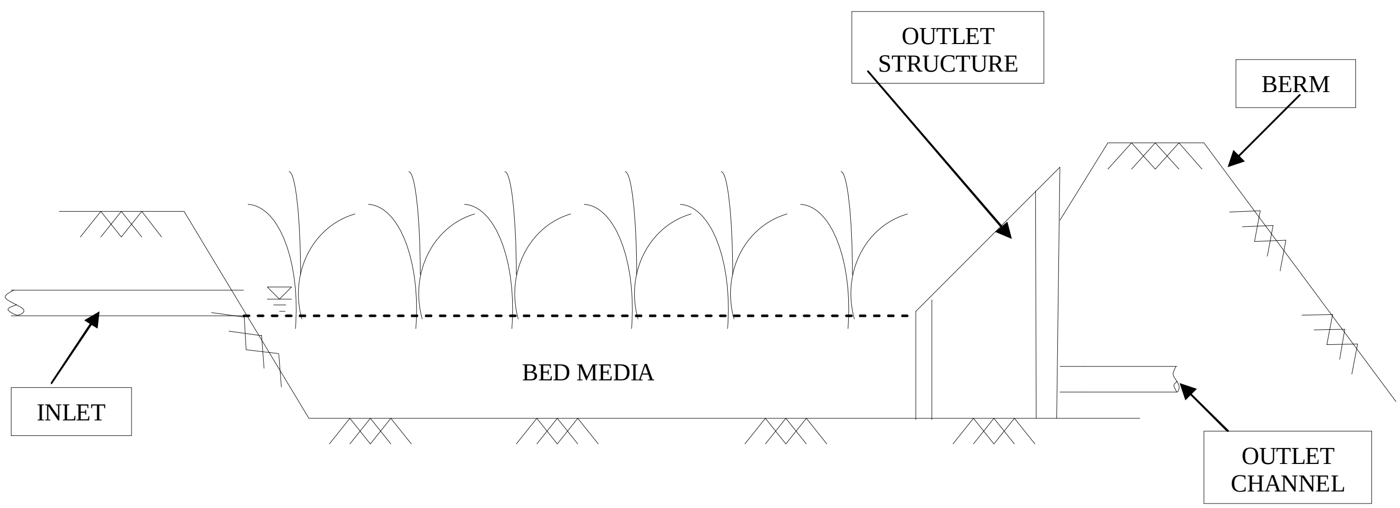


The hydrology of wetlands is generally slow flows. The wetlands are shallow (about a foot deep). This allows sediments to settle as the water passes through the wetland. The shallow depth and the slow flows in the wetlands provide an extended contact time between the pollutants and the components in the wetland and help the breakdown of both complex organic and inorganic substances.

The pollutant removal efficiency of the wetlands to a great extent depends on the vegetation in the wetland. Plants that have high growth rates and that can easily colonize the wetland are preferred. The plants should be able to establish large surface areas that continue through the winter dormant season, should have high potential for treating pollutants, and should be very robust in flooded environments. The most commonly used plants are bulrushes (*Sciprus*), spikerush (*Efeocharis*), sedges (*Cyperus*), rushes (*Juncus*), common reed (*Phragrnites*), and cattails (*Typha*) (http://www.epa.gov/owow/wetlandspdf/hand.pdf).

The natural and constructed wetlands share similarities. However they differ in some aspects (http://www.state.co.us/oemc/programs/waste/wetlands/chapter2.pdf):

1. The soil in a natural wetland may be formed as a result of weathering of rocks and minerals over a period of many years. These soils are rich in organic matter. Whereas in constructed wetlands the soil may not be as rich in organic matter as in natural wetlands.
2. In constructed wetlands plants are either seeded or planted. The vegetation in constructed wetlands is less diverse when compared to the natural wetland.
3. The type of microorganisms that thrive in a constructed wetland depends on the wastewater that is being treated in the wetland. Constructed wetlands are designed to provide an ideal habitat for the microbes to grow and perform their functions.

Three major systems involving wastewater and wetlands can be observed in the United States (Reed et al., 1985):

1. Polishing of treated effluent in natural wetlands.
2. Use of effluents or partially treated wastewater for enhancement, restoration, or creation of wetlands.
3. Use of constructed wetlands for wastewater treatment.

2.2 GRAYWATER

Graywater is all the non-toilet wastewater produced in the average household or industries including the water from bathtubs, showers, sinks, and washing machines. Most graywater systems do not use water from kitchen sink and dishwasher due to high solid concentration. The reuse of graywater can help in substantial savings in wastewater treatment.

Recycled graywater is mostly used for toilet flushing and watering landscapes. Other uses of recycled graywater include washing vehicles, fire protection, boiler feed water and concrete production (Okun, 1997, Santala et al., 1998). Graywater can also be used to develop and preserve wetlands (Otterphol et al., 1999). Reuse of graywater has many benefits (http://www.oasisdesign.net/greywater/). The use of graywater lowers the use of fresh water for toilet and landscape irrigation purposes. It lowers the pollutant load on the receiving treatment plant. Recycling of graywater utilizes less energy and chemical use.

Soaps and detergents are the main components of graywater. When used for landscape irrigation, graywater does not require extensive chemical or biological treatment. Just a side note - People typically don't treat graywater – this does not mean that graywater should really not be treated. It is not advisable to use graywater to water plants that are eaten as food as it is not disinfected.

Graywater may be immediately directed to landscaping, or it may be stored for later use. When stored, care must be taken to avoid the contamination of the water. Graywater is not recommended for use in dust control, cooling, spray irrigation, or any other use that would result in air-borne droplets or mist.

2.3 ECOLOGICAL CONCERNS

It is necessary to understand the components of a constructed wetland and the interrelationships that compose the wetland system for successful operation of the constructed wetland. Constructed wetlands are ecological systems. They combine physical, chemical and biological processes. The constructed wetlands provide a habitat for various life forms like plant, animals, microbes etc.

Periodic monitoring and maintenance of the wetlands will ensure the environmental integrity, aesthetic enhancement and wildlife benefit for future generations. The wetlands must be protected from high loads of sediments and debris. Debris, if not removed, can block the inlet and outlet structures of the wetland. The piling up of debris will also block the flow path of the water and lead to formation of stagnant pools. This may limit the functioning of the wetland. Regular trash removal from the wetland must be practiced. The presence of trash will provide unseemly conditions around the wetland and also bad odors may prevail in and around the wetland.

Wetlands provide a good habitat for a variety of insects. These aquatic insects flourish in different environmental conditions because of their diversity. Some of the groups prefer poor water quality like mosquito larvae, while some of the groups of aquatic insects (like Mayfly and Caddis fly) cannot tolerate the poor water quality condition. Insects are also attracted to wetland vegetation. Frequent initial maintenance to remove opportunistic species is typically required if a particular diverse environment is desired. Operators of wetlands may need to control nuisance insects, odors, algae and other weeds.

Mechanical protection must be provided in and around the wetland in order to restrict the entry of animals and birds like geese, deer, blackbird, and muskrat as they feed on wetland plants. Proper site preparation and preventative care will help in the maintenance of the constructed wetland. Regular maintenance is necessary to have a sound performance of the wetland.

2.4 HUMAN HEALTH CONCERNS

Aquatic environments are most suitable for mosquitoes to breed. Mosquitoes associated with wetlands create a serious health hazard to human beings. They deteriorate both internal and external environment. Mosquitoes deteriorate the external environment by creating a biting nuisance that precludes or inhibits outdoor activities and the internal environment by the transmission of pathogens that may produce disease (http://phoenix.gov/TRESRIOS/vector.html). The presence of mosquitoes in the wetland may cause a nuisance to the people visiting the wetland. This demands for immediate public health action as mosquitoes cause diseases like malaria and encephalitidies. Mosquitoes cause diseases among birds and animals like dogs, cow, cats etc.

Mosquito control strategies must be implemented in order to avoid the mosquitoes in the wetlands. The water in the wetland must not be allowed to stagnate as stagnant water attracts mosquitoes. Mosquito eating fish like the Mosquito Fish *(Gambusia)* and Green Sunfish *(Lepornis cyanellus);* can be introduced in to the wetlands. A careful inspection of the wetland must be carried out regularly. Man made control agents can be used to control mosquitoes.

Arboviruses are also a threat to humans. A significant human health concern is posed by the potential transmission of arboviruses by mosquitoes from wetland birds, which serve as reservoirs of encephalitis viruses, to domestic species (e.g., house finches and house sparrows), which are among the best hosts for virus amplification, and then ultimately to humans (http://www.innvista.com/health/microbes/viruses/arbovir.htm). Arboviruses are often associated with a range of diseases known to produce changes in the brain or cause small hemorrhages.

Protection from West Nile Viruses (WNV) is a very important concern these days. Mosquitoes are the principal carriers of this virus. Wetlands that are not maintained properly provide a habitat for those mosquito species that carry the WNV. *Culex pipiens*, the house mosquito is one the species of mosquitoes found in the East coast that carries WNV. *Culex tarsalis* is another mosquito species that prefers to breed in clean water (US EPA – Wetlands and West Nile Virus). Therefore, WNV can also spread from those wetlands that are clean and well maintained and this in turn requires the adoption of appropriate mosquito control measures. Mosquitoes primarily infect birds with the virus and occasionally from birds to humans. Whereas, the house mosquitoes can directly infect humans.

CHAPTER 3

LITERATURE REVIEW

3.1 GRAYWATER SOURCE AND QUALITY

The world is facing a crisis in water availability due to reduced rainfall, increased evaporation, changing lifestyle, urbanization and a large demand for freshwater from the population (Erikkson et al., 2002). In order to solve this problem extensive research is going on in the field of wastewater treatment, recycle and reuse in both developed and developing countries. These days importance is being given for recycle and reuse of graywater as it is less polluted and hence the treatment is easier. However, health aspects and environmental perspectives have to be considered (Erikkson et al., 2002). The graywater quality is less than the quality of tap water and is unsafe because of the presence of pathogens. However, from the literature, there are no reports mentioning about the spread of diseases because of the poor quality of graywater. The total graywater fraction has been estimated to about 75% by volume of the combined residential sewage (Erikkson et al., 2002).

Graywater has suspended solids, which can lead to the clogging of the distribution system. The risk of soil pollution is high when graywater is used for irrigation purposes leading to a high concentration of soaps and detergents in the soil which affect the plants adversely (Christova et al., 1996). Soaps are alkaline salts of long chained fatty acids and detergents are made up of a number of compounds like surfactants, abrasives, softeners, oxidants, enzymes etc. Temperature also affects the graywater quality. High temperatures favor growth of microbes. The measurements of BOD, COD and nutrients (N and P) will indicate the oxygen content. The risk of the spread of diseases is more when untreated graywater is used for irrigation and toilet flushing as graywater contains pathogenic viruses, bacteria, protozoa and helminthes. The microorganisms in the graywater can spread through air, hand to mouth contact.

Graywater composition depends on the water source, plumbing system, living habits and personal hygiene of the users. The main sources of graywater are households which includes water from bathtubs, showers, sinks (except kitchen sink), and washing machines. The characteristics of gray water will be influenced by: Cleaning products used, Dishwashing patterns, Laundering practices, Bathing habits, and disposing of household chemicals. The physical, chemical and biological characteristics of gray water and when it is used varies greatly among families and businesses.

In Colorado, graywater is regulated under the State of Colorado Guidelines on Individual Sewage Disposal Systems and applicable county Individual Sewage Disposal System (ISDS) regulations and both surface and subsurface applications require permitting and may trigger monitoring requirements
(http://www.ext.colostate.edu/pubs/natres/06702.htmlhttp://www.ext.colostate.edu/pubs/natres/06702.html)

3.2 WETLAND APPLICATIONS

Much importance is being given to treat wastewater using natural, low cost, low energy methods. Wetlands are being used extensively as natural purification barriers to improve water quality and to reduce the impact of effluent and runoff on receiving water quality. Wetlands provide habitat, food, and breeding areas to a variety of animal and plant species. They also provide important services to society and are crucial for sustaining and improving water quality.

To manage low strength contaminated waters a more appropriate technological approach is to create and/or utilize complex ecosystems which can immobilize and transform nutrients and other pollutants, sustain low maintenance and energy inputs and have a high degree of homeostasis (Hansen and Kjellerup, 1994). Constructed wetlands are a prime example of the ecological engineering technique to treat water and wastewater.

Current applications of Constructed wetlands include treatment of: municipal wastewater, acid mine drainage, stormwater, primary settled and secondary treated effluent, tertiary effluent polishing, urban and rural runoff management, land-fill and mining lecheate treatment, toxicant management, sludge management, industrial effluent treatment, enhancement of in stream nutrient assimilation, nutrient removal and groundwater recharge. In the present study wetland treatment is being applied to treat the graywater arising from the bathroom sinks in the Atmospheric Sciences Building, Colorado State University, Fort Collins, Colorado.

3.3 WETLAND TREATMENT OF WASTEWATERS

Constructed wetlands are applied for treatment of a variety of wastewaters. Constructed wetlands are generally used as a finishing component in the treatment process of municipal wastewater. A four year research project was carried out in Everstekoog, Netherlands to change effluent from an oxidation ditch to reusable surface water using a constructed wetland (Raud et al., 2000). The constructed wetland increased the water quality of the effluent coming out of the oxidation ditch. The wetland improved the oxygen regime, the effluent was found to obtain a diurnal pattern of oxygen as long as the sunlight could reach the submerged plants. Longer hydraulic retention times (HRT) were more effective in removal of ammonium, nitrate and E.coli in wintertime. In wintertime the turbidity increased because of the production of biomass. With a HRT of two days in summer and with a HRT of four days in winter a substantial amount of nitrogen was removed. Whereas, for stable phosphorous removal a longer HRT was needed in all seasons. The constructed wetland in the Everstekoog system was an attractive system. One of the features of the constructed wetland was that it combined recreation areas with wildlife.

Extensive research has been carried out in using constructed wetlands to treat stormwater. Stormwater runoff contains a variety of pollutants like BOD, suspended solids, nitrogen, nitrate and nitrite, phosphorous, lead, zinc, chromium, cadmium, iron, mercury, nickel, phenols, cyanides, soaps, pesticides, herbicides, fertilizers and oil and grease. The type of pollutant targeted to be treated influences the design of the wetland. Stormwater wetlands are also designed to improve the water quality, improving the flood control, enhancing wildlife habitat, providing recreation and education.

Studies in North Carolina (http://www.neuse.ncsu.edu/SWwetlands.pdf) indicate that constructed wetlands to treat stormwater are effective BMPs. They reported that stormwater wetlands have the best removal rate for total suspended solids, nitrate-nitrogen, ammonia-nitrogen, total phosphorous, phosphate-phosphorous, and some metals. Also from the data collected by Wong et al., 1999 showed that effective removal of total suspended solids (TSS), total phosphorus (TP) and total nitrogen (TN) was achieved. Results showed that the effectiveness of a wetland system appeared to be most influenced by the catchment runoff characteristics of the respective site (i.e. the combined effects of climate, catchment size and land use), as well as the design and surface area of the wetland or pond system.

In 2000, Stone et al. considered constructed wetlands to treat swine lagoon wastewater. The constructed wetland was effective in reducing total nitrogen and ammonia-nitrogen with efficiencies greater than 75%. They were not as efficient in treating total phosphorous. The parameters for major design models were estimated from constructed wetland data, and were found close to those in the literature for TN and NH_4-N. The design parameters for TP were found to be higher than those reported in the literature. The design parameters were calculated based on the first-order area-based uptake equations. First-order area-based rate constants were found to be close agreement with those in the literature.

The Sacramento Constructed Wetlands Demonstration Project (SCWDP) gave an overview of the demonstration wetland project along with background information on treatment wetlands and trace metals, the project results and a summary on the major findings in the executive summary of the five – year summary report 1994-1998. A 22-acre site in the buffer lands that surrounded the Sacramento Regional Water Treatment Plant (SRWTP) was chosen as the wetland area. Multiple wetland cells were incorporated for the project. The influent into the wetland cells was the ultraviolet-light disinfected secondary effluent from the SRWTP. The wetlands were monitored for water quality, sediment quality, vegetation characteristics, and habitat use.

The wetlands in the SCWDP were monitored for fifteen trace metals: antimony, arsenic, copper, beryllium, cadmium, chromium, iron, manganese, lead, mercury, nickel, selenium, silver, thallium and zinc. The concentrations of the toxic metals entering the wetland were low and none of them exceeded the California Toxics Rule (CTR) ambient water quality criteria. Zinc, copper and nickel accounted for 90% of the annual average 11.2 lb/ac-yr mass loading of metals in the secondary effluent applied to the treatment wetlands. The effluent total metals concentrations were compared with the ambient water quality criteria found in the 1997 draft of the CTRs complete compliance. The mass removal rates for the metals (silver, cadmium, copper, mercury, lead and zinc) consistently exceeded 60%. For arsenic, chromium and nickel, the concentration and mass removal rates were found to decline steadily. This was attributed to their presence in the wetland in a soluble form and a chemistry that inhibits their removal from solution. The water column investigations indicated that removal of nickel was achieved in spite of its resistance to removal. There was a significant reduction in copper which is weak organically complexed and a 60% reduction in hexavalent chromium concentration despite little apparent removal of total chromium concentrations.

In 1998, the renovation of North Golf Course in Purdue University included a series of constructed wetlands that served as both water hazards and water quality management tools

(Reicher et al., 2005). This study was used to determine the chemical characteristics of the water in the constructed wetlands which was associated with a golf course and a residential area. Also the study focused on tracking the water quality changes through the wetland system during storm and non-storm events.

The wetlands were found to efficiently remove 97% of $N\text{-}NO_3/NO_2$ and 100% of $N\text{-}NH_3$. The water exiting the golf course during storm events was not a major source of contamination to the Cuppy-McClure watershed in spite of runoff, fertilizer and pesticide inputs on the golf course. This was attributing to the lower storm water concentration for 13 of the 17 parameters (except potassium, alluminium, magnesium and silicon) that were found leaving the golf course than entering. During the non-storm event only once there was pesticide detection at the downstream of the first wetland. The pesticide was dinitroaniline herbicide trifluralin. The pesticide was not applied to the golf course and the source from where the pesticide came was not detected. The wetland system on the golf course was found to be effectively used to filter golf course tile drains, as well as runoff from areas adjacent to the course.

From the literature it can be inferred that the constructed wetlands are very efficient in removing nitrate-nitrogen, nitrite-nitrogen and ammonia-nitrogen. Phosphorous is not removed completely. Trace metals were also found to be removed efficiently. Longer HRTs resulted in efficient removal of ammonia, nitrate and E. coli in winter season.

CHAPTER 4

DESIGN CRITERIA

The wetland design criteria includes:

- The wetland design should have a buffer zone to separate the wetland from the surrounding land. The trees in the buffer area of the wetland help minimize species which are invasive and eliminate other species of plants and minimize the disruption to wildlife.
- A Geosynthetic Clay Liner is provided as a liner in order to protect the infiltration into the groundwater.
- At the inlet of the wetland, a forebay must be provided to collect the incoming graywater. This pool contains 5% of the wetland volume. The forebay is separated from the remaining part of the wetland by a vegetative berm located at a distance of a foot from the inlet. The inlet to the wetland is positioned below the frost line.
- Another vegetative berm is installed at the center of the wetland.
- A micropool is to be provided at the outlet. The pool must contain 10% of the wetland volume. The vegetative berm is installed along the micropool.
- The vegetation in the wetland are emergent.
- The flow in the wetland is distributed uniformly using V-shaped channels installed in the berms. Three channels are installed in each of the berms located at the inlet and at the center of the berm each discharging one-third of the average flow. At the berm surrounding the micropool two channels are installed.
- A 90 degree V-notch weir is designed as the outlet structure. The water level in the notch will help in determining the flow at any given point of time.
- The bottom of the V-notch is placed at 1.6ft. This is the water height at average flow.
- The V-notch plate is positioned in a concrete box. The top of the box is covered with a thrash rack with 1” by 1” openings.
- The water collected in the outlet chamber is conveyed to the main sewer by a bottom drain pipe.
- In order to avoid excess flow through the wetland the stormwater is diverted at the inlet of the wetland.
- Before starting the construction of the wetland, the permitting agencies that set the monitoring plan and the discharge standards must be contacted.
- The design includes three sampling stations. One at the inlet. The second one at the center of the wetland (the central vegetative berm) and the third at the outlet. The sampling location at the center of the wetland is optional.

CHAPTER 5

WETLAND DESIGN

5.1 PHYSICAL FACILITIES

The site topography is of important concern in determining the wetland location. The site topography dictates the shape and configuration of the wetland. Steep slopes are to be avoided as they deter the plant growth in the wetland. Also, this leads to increased construction costs, harvesting and maintenance problems.

The aspect ratio (AR) is the average length divided by the average width of a wetland system. The higher the length to width ratio of the wetland short circuiting is minimized. The AR for this current wetland project was assumed to be 3:1. The higher AR allows the wetland to closely perform plug flow hydraulics (Gearheart and Finney. 1996).

As previously mentioned, the site topography plays an important role in determining the shape of the wetland. The land configuration and surrounding land use activities also are important factors to be considered. However, there is no particular shape of a constructed wetland that is preferred to achieve the desired effluent quality. Whereas design considerations like hydraulic retention time, short-circuiting, inlet/outlet structures, internal and surface configurations can significantly impact the effluent quality.

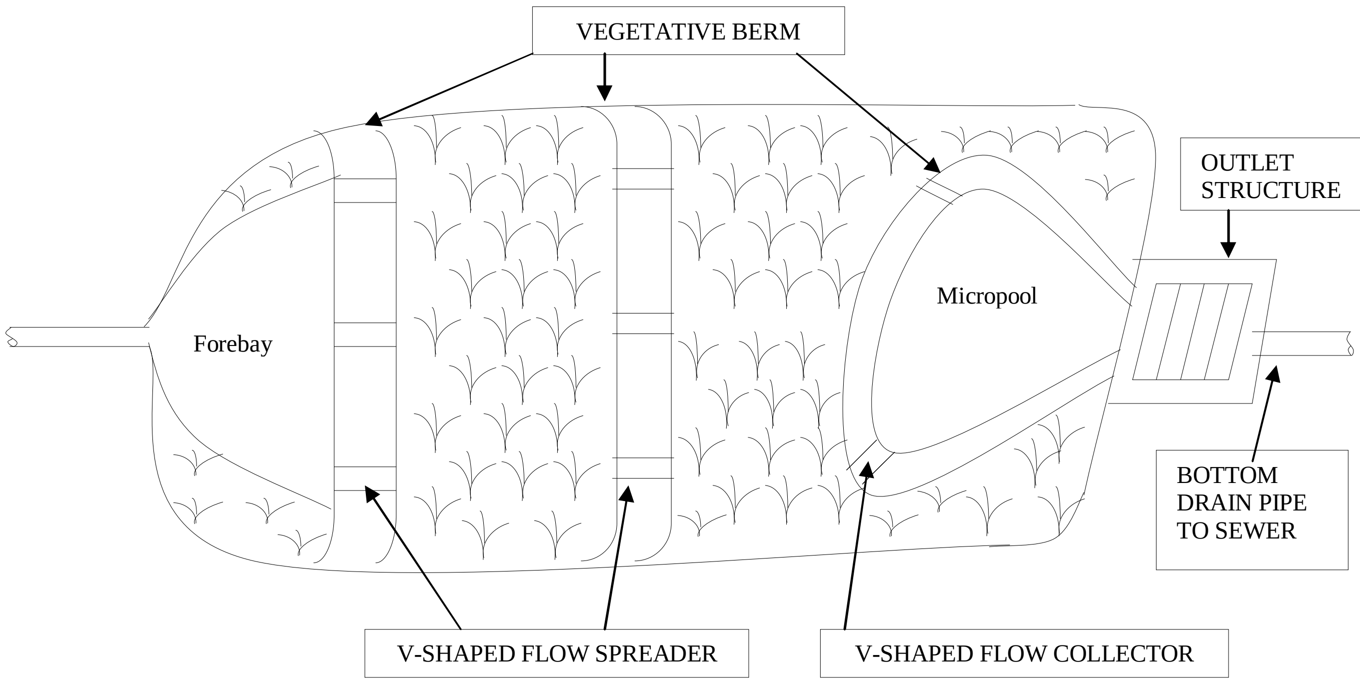
The City of Fort Collins is located at latitude of 40.54N and at a longitude of 105.07W, receives average snowfall of about 51 inches per year (http://www.payneinvestments.com/relocation.htm) and thus the climate is an important factor of concern. Wetlands are highly influenced by climate. Rainfall, snowmelt, spring runoff, drought, freeze, and temperature can all affect wetland treatment. Snowmelt and rainfall decrease the wetland efficiency. Latitude is the most critical parameter affecting the climate as it determines seasonal temperature ranges. The long-term average temperature during the coldest month of the year has been found to be a good estimator of the critical low water temperature that will be experienced in a wetland system (Kadlec & Knight, 1996). For areas where the minimum annual average monthly temperature is less than zero, it can be assumed that the minimum wetland operational temperature will be lightly above zero under an ice cover (Kadlec & Knight, 1996).

Snowmelt and spring runoff can resuspend and export stored pollutants. Runoff during spring may carry more than half the annual nitrate and phosphorus exported during the year and suggests that wetland management should focus on this time of the year (Jacobson, 1994). The runoff in excess of maximum design flow is diverted around the wetland to avoid excessive flows through the wetland.

Wetlands continue to treat water during cold weather. However, freezing temperatures in winter and early spring can reduce treatment if the wetland either freezes solid or a cover of ice prevents the water from entering the wetland. If under-ice water becomes confined, water velocities may increase, thereby reducing contact times.

The plan and profile of the wetland system is shown in figure 2a and 2b. The different sections in the wetland are shown in figures 2c, 2d and 2e.

FIGURE 2A
PLAN



WETLAND DIMENSIONS: 4.93m*1.64m*0.8m

FIGURE 2B
PROFILE

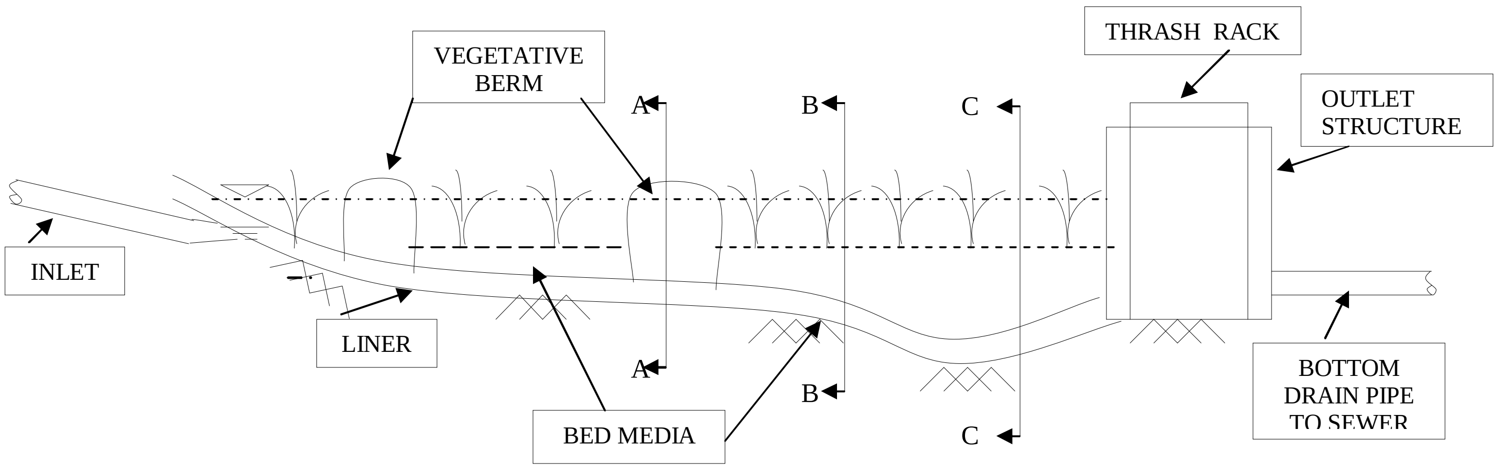


FIGURE 2C

SECTION A-A

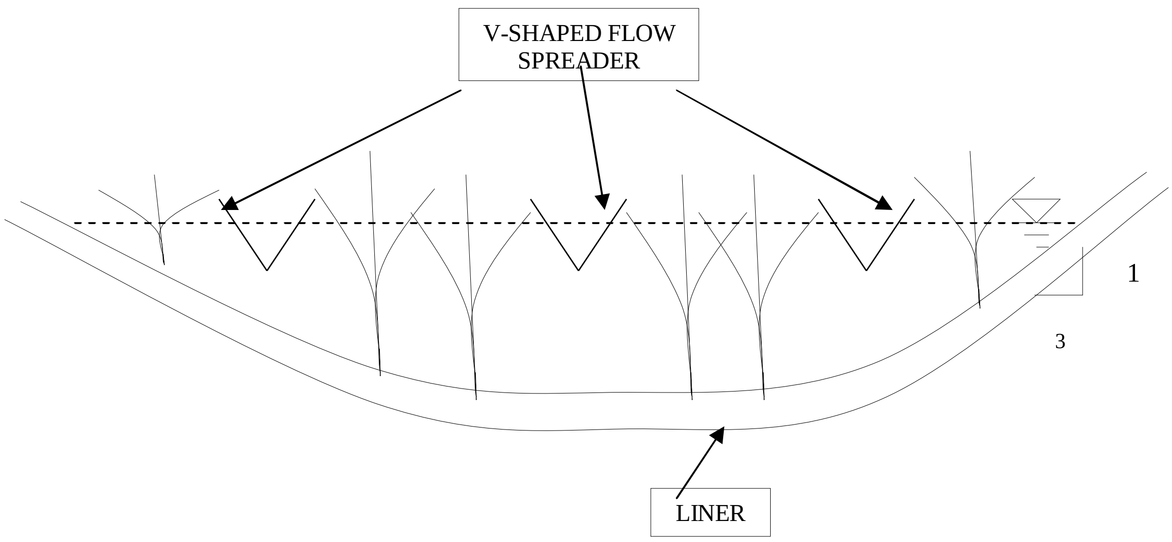


FIGURE 2D

SECTION B-B

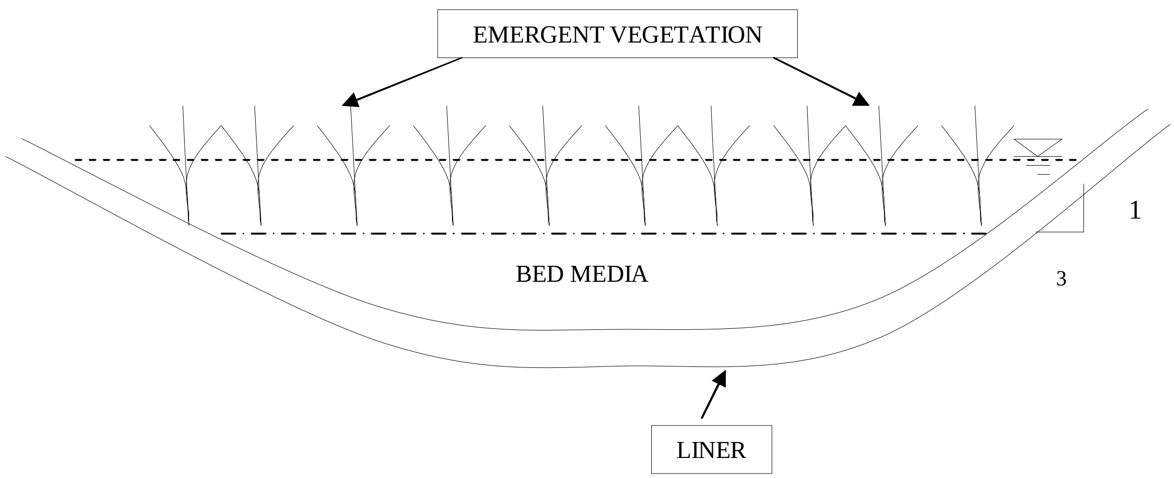
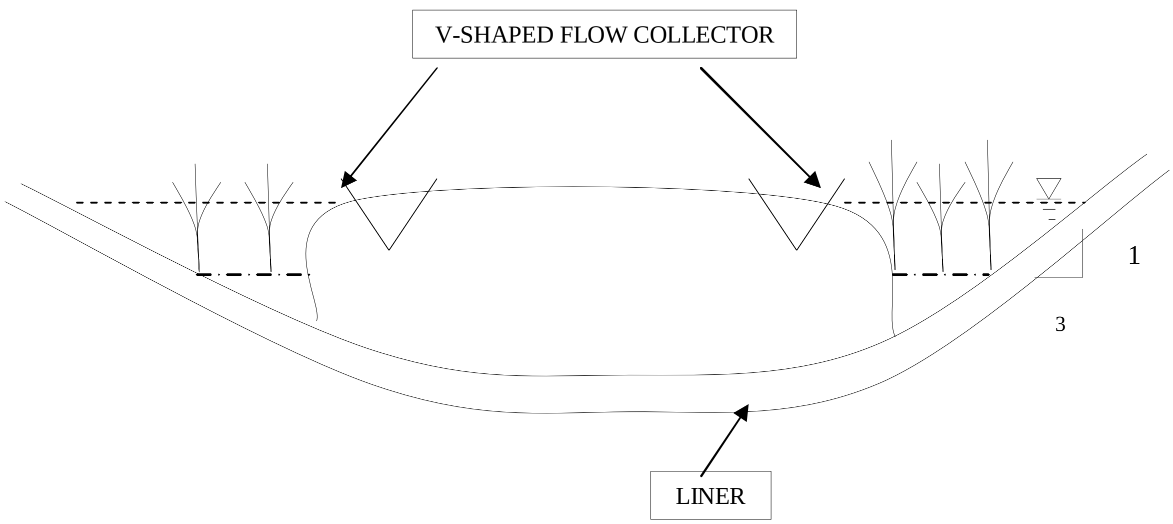


FIGURE 2E

SECTION C-C



5.2 INLET

The inlet of the constructed wetland has a forebay which allows the sediments and other solids to settle down. The forebay contains 5% of the wetland volume and must be 4-6 ft deep. The inlet and the outlet must be located far apart in order to avoid short circuiting. Also, to minimize short circuiting a uniform distribution of flow must be established across the entire width of the wetland inlet. This helps in reducing the flow velocities and delivers a uniform flow across the downstream of the wetland.

A barrier, such as an earthen berm, gabions, or a concrete weir may be used to separate the forebay from the permanent pool (Connecticut Stormwater Quality Manual, 2004). The barrier should be resistant to erosion. A vegetative berm will be installed near the forebay at about a foot from the inlet. There are pipes installed in the berm in order to distribute the graywater uniformly across the wetland.

Generally, for cold climate conditions a perforated inlet manifold is used as an inlet structure. The inlet pipe to the wetland is positioned below the frost line to prevent the pipe from freezing (Connecticut Stormwater Quality Manual, 2004). An accessible cleanout is to be provided for cleaning the inlet.

5.3 OUTLET

The outlet determines the flow rate coming out of the wetland. A 90 degree V-notch weir is installed as the outlet structure and the water level in the notch will help in determining the flow rate at any given point of time. The V-notch details are shown in figure 3a. The V-notch plate is positioned in a concrete box that is available in the market. A stilling well is attached to the V-notch which is a sampling unit. The purpose of a stilling well is to record the head readings. The top of the box is covered with a thrash rack with 1” by 1” openings. Trash racks are installed at a shallow angle to prevent ice formation. The water collected in the outlet chamber is conveyed to the main sewer by a bottom drain pipe (figure 3b).

The V-notch angle was determined by calculating the average discharge by varying the water level in the V-notch (Appendix 1). The average discharge and the corresponding water level were calculated for different V-notch angles (θ, table 1). The discharge was calculated using equation (1)

$$\mathbf{Q = C_d*(8/15)*\sqrt{2g}*H^{2.5}*Tan\ (\theta/2)} \qquad \text{equation (1)}$$

Where,

Q = average flow

C_d = coefficient of discharge

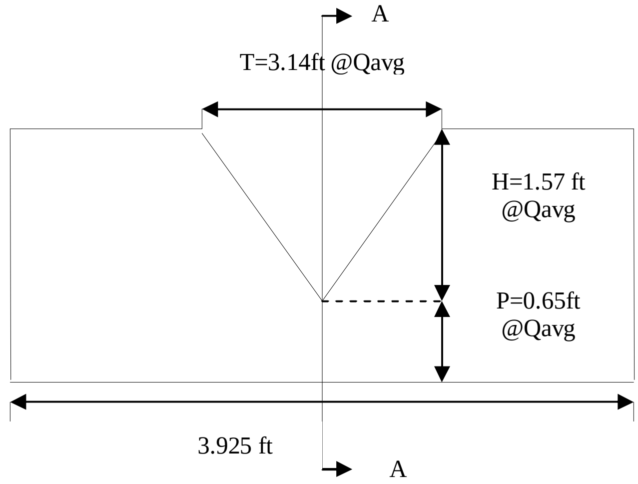
g = acceleration due to gravity

H = the water level in the V-notch

θ = notch angle

FIGURE 3a

V-NOTCH DETAILS



SECTION A-A

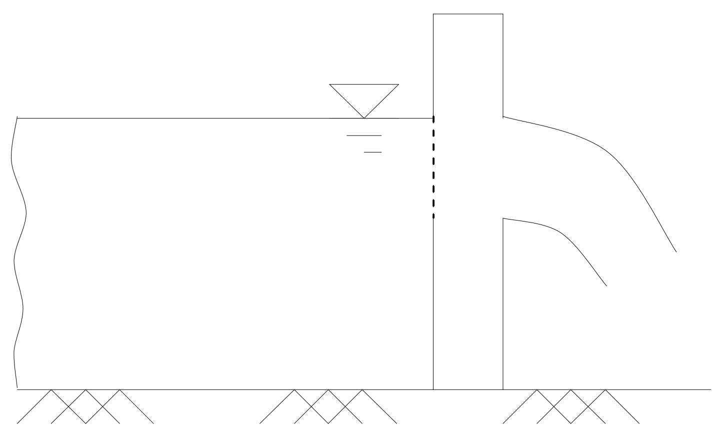
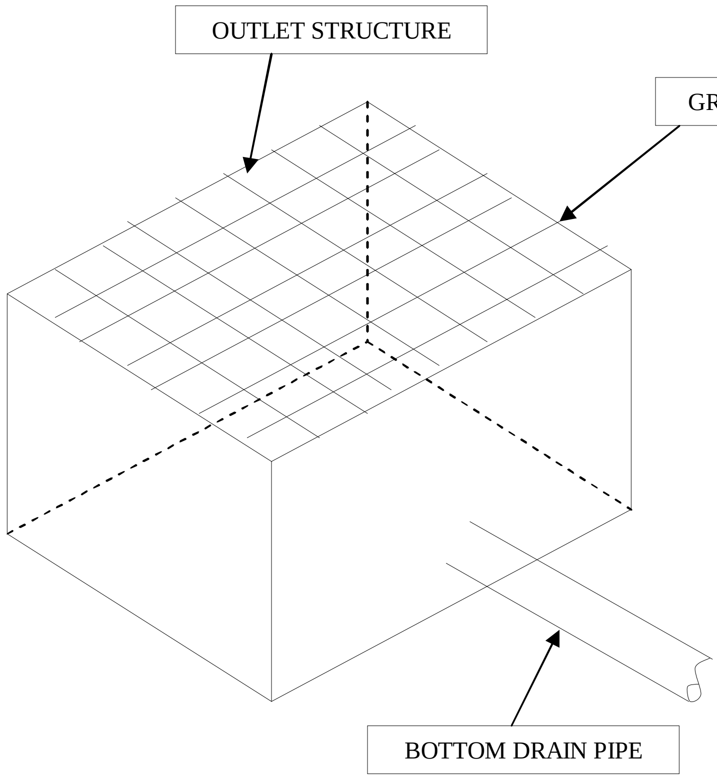


FIGURE 3b

OUTLET STRUCTURE WITH THE BOTTOM DRAIN PIPE



The water level at average discharge (Qavg) and at plus/minus 15% of the average flow was calculated (Appendix 1). Table 2 the values of the water levels at Qavg and at plus/minus 15% of the average flow. The C_d value was taken as 0.581, the minimum value for all angles (Lenz, 1943).

TABLE 1: COMPARISON OF H VALUES AT Qavg FOR DIFFERENT ANGLES

θ(in degrees)	H @ Qavg (ft)
10	4.16
20	3.14
30	2.65
45	1.98
60	2.14
90	1.57

TABLE 2: VALUES OF H FOR A 90 DEGREE V-NOTCH

	Qavg	0.15*Qavg	Q(-)-Q avg	Q(+)+Q avg
	7.63	1.15	6.48	8.78
H(in ft)	1.568		1.469	1.659

The discharge values are in cubic feet per day (cfd)

The width of the weir plate was calculated using the guideline H/B<=0.4, where B is the width of the weir plate. The width of the plate was found to be 3.93 ft at Qavg. The distance "P" between the bottom of the V and the weir plate was calculated using the guideline H/P<2.4 (http://www.lmnoeng.com/Weirs/vweir.htm).The value of P was found to be 0.65 ft at Qavg.

The top width of the V-notch was calculated as

$$T=2*H*Tan\ (\theta/2) \qquad \text{equation (2)}$$

Where

T = top width of the V-notch
H = the water level in the V-notch
θ = notch angle

The value of "T" was found to be 3.14 ft at Qavg.

A micropool is incorporated before the outlet. This must contain 10% of the wetland volume. A vegetative berm is constructed across the micropool. V-shaped flow collectors are installed in the berm to collect the treated graywater in the pool from all sides of the constructed wetland.

5.4 WETLAND BODY

The anticipated characteristics of graywater coming out from the Atmospheric sciences building are presented in table 3.

TABLE 3: CHARACTERISTICS OF GRAYWATER

PHYSICAL PROPERTIES	CHEMICAL PROPERTIES	BIOLOGICAL PROPERTIES	NUTRIENTS
• Turbidity • Total Suspended Solids • Total Solids • Volatile Solids • Total Dissolved Solids • Temperature • Color	• pH • Biochemical Oxygen Demand • Chemical Oxygen Demand • Total Organic Carbon • Inorganic Carbon	• Total Coliform • Fecal Coliform • E. Coli	• Ammonia nitrogen • Nitrate Nitrogen • Total Phosphorous

The EPA manual (EPA Manual, 2000) was referred for the wetland design. Areal Loading Rates (ALR) was applied to average flow and maximum flow conditions to identify the critical conditions for sizing of the facility.

There are anticipated to be about 38 people to be working in the Atmospheric Science Building. The average production of graywater per person is assumed to be 1.5 gal/cap/day. The peak flow was calculated assuming a peak factor of 1.5. The average flow and the peak flow are 0.21603 m3/day and 0.324045 m3/day respectively. The ALR analysis was carried out for Biochemical Oxygen Demand (BOD) and Total Suspended Solids (TSS). The detailed design of the wetland is presented in Appendix 2.

The average BOD (129 mg/L) and TSS (79.2 mg/L) values were determined from E. Eriksson et al [39]. The maximum BOD and TSS values were 100 mg/L and 30 mg/L respectively. The total area of the wetland was calculated using the equation

$$\mathbf{ALR} = \frac{\mathbf{Q*C_0}}{\mathbf{A_w}} \qquad \text{equation (3)}$$

Where

ALR = areal loading rates: BOD = 40 kg/ha-day; TSS = 30 kg/ha-day
Q = incoming flow rate, in m^3/d
C_0 = influent concentration, in mg/L
A_w = total area of FWS, in ha

The total area was calculated for both average and maximum flows. The total area was found to be 0.00081 ha or 87.16 cu-ft.

Assuming the average depth of the wetland to be 0.8m and the length to width ratio to be 3:1, the size of the wetland was determined to be 4.93m*1.64m*0.8m. The retention time is 11.44 days.

The hydraulic retention time (HRT) was calculated from equation (4)

$$\mathbf{t = \frac{V_w * \varepsilon}{Qave}} \qquad \text{equation (4)}$$

Where

t = hydraulic retention time
V_w = wetland volume
Qave = average flow rate
ε = wetland porosity

The hydraulic retention time was calculated for both average and maximum flow rates, 25 days and 16.67 days respectively.

Shallow slopes will help in better plant establishment in the wetland and will produce a more natural wetland appearance.

The inlet and outlet structures must be placed far apart in order to avoid short circuiting.

The vegetation pattern in the wetland is shown in figure 4. The wetland body includes a forebay near the inlet and a micropool at the outlet. The forebay at the inlet contains 5% of the wetland volume and the micropool at the outlet contains 10% of the wetland volume.

Three berms are installed in the wetland (figure 2a). One berm at the inlet, the second at the center of the wetland and the third along the micropool. The graywater is allowed to flow from one part of the wetland to the other through the flow spreaders installed in the berms (figure 2c and 2e). V-shaped channels are used as the flow spreaders. There are three flow spreaders at each of the berms at the inlet and at the center of the wetland. Each flow spreader designed to carry one-third of the average flow. There are two V-shaped flow collectors installed in the berm along the micropool to collect the treated water. The vegetation in between the berms is emergent. The treated graywater is connected to the sewer by a bottom drain pipe. The bottom drain pipe is placed at the bottom of the outlet structure as shown in figure 3b.

5.5 VEGETATION

The vegetation in the wetland must be able to remove pollutants and nutrients present in the graywater and provide a diverse habitat within the constructed wetland. Plants with high growth rates, can establish large surface areas and can withstand winters must be used. Regular harvesting of the vegetation in the wetland stimulates the growth of plant species and in turn helps in the removal of accumulated nutrients and excess organic matter. The vegetation in the wetland attracts wildlife.

The most common plants used in constructed wetlands are bulrushes *(Scirpus),* spikerush *(Efeocharis),* and other sedges (Cyperus). Rushes *(Juncus),* common reed *(Phragrnites),* and cattails *(Typha).* Other wetland species that have been used are shown in table 4.

TABLE 4: CONSTRUCTED WETLAND PLANT SPECIES (adapted from Schueler 1992 and Thunhorst 1993).

Common name	**Scientific name**
Arrow arum	*Peltandra virginica*
Arrowhead/duck potato	*Saggitaria latifolia*
Common three-square bulrush	*Sciprus pungens*
Softstem bulrush	*Sciprus validus*
Blue flag iris	*Iris versicolor*
Broad leaved cattail	*Typha latifolia*
Narrow leaved cattail	*Typha augustifolio*
Reed cabary grass	*Phalaris arundinocea*
Lazard's tail	*Saururus cernuus*
Pickerelweed	*Pontedaria cordota*
Common reed	*Phragmites australis*
Soft rush	*Juncus effuses*
Spikerush	*Eleocharis palustris*
Sedges	*Carex spp.*
Spatterdock	*Nuphar luteum*
Sweet flag	*Acorus calamus*
Wild rice	*Zizania aquatica*

Any species of plant that grows well and establishes dense vegetation may be selected to treat wastewaters. Bulrushes can establish themselves easily and are not invasive. They are recommended to treat wastewaters as they can withstand high levels of nutrients. The wetland edges can be planted with Blueflag iris as they provide color. Cattails and common reed have been used frequently because of their high tolerances for many types of wastewater, but both have disadvantages. Both are invasive. Cattails are subject to attack by army worms as well as insects (Surrency, 1993).

The common wetland plants found in Colorado are listed in table 5 (http://waterknowledge.colostate.edu/plants.htm). The grass or the grass like plants can be used to treat the graywater. Cattails can be used for removal of nutrients as they have high nutrient tolerance levels. From the past studies, it can be inferred that cattails have been used extensively. The blueflag iris can be planted along the constructed wetland edges to provide aesthetic value to the wetland and also provide color.

TABLE 5 COMMON WETLAND PLANTS FOUND IN COLORADO

Grasses and Grass like Plants	Wetland Shrubs and Trees	Herbaceous Flowering Plants
Canadian reed-grass	Alder	Water hyssop
Cattail	River birch	Marsh marigold
Saltgrass	Shrubby cinquefoil	Cow parsnip
Beaked sedge	Willows	Wild iris
Spikerush		Bluebells
Cliff sedge		Water cress
Horsetail		Buttercup
Nebraska sedge		Star gentian
Common reed		
Water sedge		
Bulrush		
Wooly sedge		

The wetland vegetation species are to selected based on the water regime, climate, soil type, and the interaction between basin bathymetry, outlet hydraulics and catchment hydrology – the hydrologic regime.

Wetland vegetation can be established by the following methods (Wong et al., 1999)
Direct seeding

- Seedlings
- Transplantation of harvested material and transplanting wetland sediment seed banks.
- Nursery stock

Nursery stock provides well established vegetation in the wetlands. The planning and ordering of the stock must begin early in the wetland system design phase as they require time to establish themselves.

Direct seeding is the cheapest method for establishment of vegetation in the constructed wetland. This method is not reliable as germination of seeds is unpredictable. There is a risk of failure due to flooding, drying, seed predation and fungal attack. Also, direct seeding is vulnerable to weed invasion.

Transplantation of harvested materials is a cost effective method of vegetation establishment. This method involves labor costs and is most suited to establishing small areas. Species with rhizomes, tubers or entire plants are most successfully established using this technique. One of the advantages of this method is that the transplanted material can be directly planted in the wetland. The disadvantages include damage to the plant species while handling and there are a limited number of species.

Timing of planting is a very important factor to be considered for the successful establishment of the wetland vegetation. Early spring is the ideal season for planting.

The control of the water level is the most important to maintain the wetland vegetation. High water levels may lead to the invasion of weeds. Issues that require continual attention include vegetation composition, accumulation of organic matter and sediment, variations in hydraulic behavior, and the development of potential pest habitats.

The wetland vegetation can be harvested regularly in order to have a sound performance of the wetland. Harvesting can be done when the plants in the constructed wetland are highly enriched with nutrients. This can be found out when the samples analyzed result in high concentrations of the pollutants. In order to harvest the plants in the constructed wetland, the wetland has to be dewatered. To accomplish this task and on the availability of the funds, drains can be installed in the wetland.

5.6 LINER

A liner is provided to the constructed wetland in order to avoid infiltration into the groundwater and prevent the groundwater contamination. A Geosynthetic Clay Liner (GCL) is recommended as a liner. A GCL consists of clay material, usually bentonite, woven between two geotextile layers. GCLs require soil cover of at least 300mm to provide sufficient normal force to confine the expansion of the bentonite core layer (http://ancid.org.au/seepage/4_2__2_geo.html).

Sodium bentonite clay is a natural occurring clay mineral that swells as the water enters between its clay platelets. When hydrated under confinement, the bentonite swells to form a low permeability clay layer with the equivalent hydraulic protection of several feet of compacted clay (http://www.fieldliningsystems.com/clayliner.html).

The major advantages of GCLs are the more consistent physical properties, the lower leakage rates, the faster installation, and the reduced construction quality assurance (CQA) requirements. These features make GCLs very attractive hydraulic barrier materials (http://www.cv.nctu.edu.tw/english/faculty/Papers-pdf/gcl-ka.pdf). The disadvantages of GCL are that they are heavy, difficult to handle, and labor intensive to install (http://ancid.org.au/seepage/4_2__2_geo.html).

The GCLs have been used as the sole hydraulic barrier layer in many cases (Daniel and Scranton, 1996). While applying the GCL for a constructed wetland care must be taken while pulling the plants out from the wetland in order not to scrape the liner off.

5.7 STORMWATER DIVERSION

The constructed wetland in the current project does not consider the treatment of stormwater. The stormwater is diverted away from the wetland which in turn reduces the load on the constructed wetland, and the damage to the wetland vegetation.

The stormwater is diverted at the inlet. The inlet provides a hydrologic flow control of the inflow into the wetland. A by-pass weir is to be provided at the inlet along with a stormwater diversion channel in order to avoid the stormwater from entering the wetland.

5.8 SAMPLING PLAN

The sampling stations are located at the inlet and the outlet. One more sampling station can be installed at the berm located at the center of the wetland. The berm at the center has three flow spreaders installed. Each flow spreader can have a hose connected to collect the samples. The frequency of sampling has been discussed in the Wetland Monitoring section.

CHAPTER 6

WETLAND MAINTENANCE.

Periodic monitoring and maintenance of the wetlands will ensure the environmental integrity, aesthetic enhancement and wildlife benefit for future generations. A detailed plan of the constructed wetland inspection and maintenance must be laid out. The key maintenance considerations of a constructed wetland system are the flow and the vegetation. Weed control and debris removal are the important jobs to be performed. For the constructed wetland to perform successfully following factors must be considered:

- Flow must be uniformly distributed throughout the wetland.
- The graywater being treated must be in sufficient contact time with the vegetation and the microbial community in the wetland.
- A healthy ecosystem must be maintained in the wetland ecosystem.

The wetland has to be checked after high flows and after ice break – up as it may lead to scouring at the inlet and the outlet structures. The slope at the inlet pipes can be increased by 1% if required to avoid water from standing within the pipe and reducing the potential for ice formation. The trash racks must be installed at a low angle to avoid ice formation. The outlet structure must not have any corrosive metals and the outlet structures must be resistant to ice and frost (Connecticut Stormwater Quality Manual, 2004). Also the trash rack has to be cleaned regularly.

The wetland must be regularly inspected for the build up of debris. This may lead to obstruction of flow in to the wetland. The stagnant water will attract mosquitoes and decreases the pollutant removal efficiencies. Accumulation of debris will clog the inlet and outlet structures. When there is a high concentration of pollutants particularly nutrients, the plants are to be harvested. Also the dead plants are to be removed.

The insects are attracted to the wetlands. Mosquitoes are the most attracted. Stagnant waters provide a very good habitat for them. The water in the wetland must be kept flowing in order to prevent the formation of stagnant pools. Shading of the wetland area is helpful in avoiding the mosquitoes. The water quality in the wetland must be able to maintain the mosquito feeding fish. The use of insecticides in constructed wetland is not recommended as they easily adsorb onto the organic matter and degrades the water in the wetland.

The wetland must also be inspected for the accumulation of litter in and around area surrounding the wetland. This will attract harmful insects and microbes which in turn lead to the spread of diseases. Litter accumulation must be avoided in order to attract people visiting the wetland.

Preventative weed control must be adapted as it is the most effective means of saving money and perpetuates the value of a planted site. The forebay depth must be 4ft or greater. This helps keep away the invasive emergent vegetation. Herbicides can be used if required with care as they can damage the wetland vegetation.

Maintenance of the wetland vegetation is very important. The water depth in the wetland plays a significant role to maintain the vegetation. The water level in the wetland must be maintained. Slight changes in the water depth are acceptable. Care must be taken not to exceed the tolerance limits of certain species for extended periods of time as it may cause damage to the vegetation (Constructed wetlands handbook, 1995). Also, mechanical protection must be provided in and around the wetland in order to restrict the entry of animals and birds like geese, deer, blackbird, and muskrat which feed on wetland plants.

Sediment and erosion control methods must be better used to remove the sediments from the forebay and the micropool. The inlets and outlet structure are prone to build up of litter. The removal of litter and debris must be carried out regularly. Trees along the buffer area help in erosion control.

CHAPTER 7

WETLAND MONITORING

Monitoring of a constructed wetland system is very important to ensure sound performance of the system. The wetland is monitored for both the facilities and parameters i.e. the pollutants present in the graywater. Monitoring will help in identifying the problems in the wetland and thereby improve the treatment facility. Monitoring of the constructed wetland indicates the integrity of the wetland ecosystem. Since the wetlands form an interface between the land and water environments they require regular monitoring and surveying techniques.

Monitoring is integral to the success of an effective adaptive management strategy. Without valid monitoring data, management actions may or may not result in improved conditions or compliance with regulatory permits.
(http://www.wsdot.wa.gov/environment/biology/docs/MethodsWhitePaper052004.pdf)

A detailed monitoring plan is to be laid out before the construction of the wetland and the details are to be discussed with the State and Regulatory agencies. The discharge compliance, the parameters to be monitored and the frequency of sampling are to be discussed with the permitting agency.

Monitoring parameters are measured to assess the system's structure and function relative to the performance criteria (Systematic Approach to Coastal Ecosystem Restoration 2004). The monitoring criterion of the wetland includes water quality, sediment quality, temperature, hydrology, inflow and outflow rates, water level, vegetation, habitat structure and diversity. The water level in the constructed wetland is to be monitored regularly in order to maintain the health of the vegetation.

Screening the wetland visually is an important part of the monitoring. It helps in identifying areas that need immediate remedial action (EPA Volunteer Wetland Monitoring, 2001). Bioassessment tests can be adopted to identify the damages caused to the wetland by human beings. Flow pattern monitoring can be done by means of tracer studies.

FREQUENCY OF SAMPLING

There can be proposed to be three sampling locations in the constructed wetland. First at the inlet the second one at the center of the wetland (the central vegetative berm) and the third at the outlet. The sampling location at the center of the wetland is optional. Three hose pipes can be installed at each of the V-shaped flow spreaders to collect the samples.

A stilling well will be installed at the outlet structure for sampling. Weekly samples must be taken at the outlet and at the inlet. At the center of the wetland periodic (monthly) samples may be taken (EPA Manual, 2000). Monitoring for mosquitoes and vegetation can be done on a regular basis (EPA Design Manual, 1998). The other parameters to be monitored other than biochemical oxygen demand (BOD_5) and suspended solids (SS) can be discussed with the State and Regulatory agency. A summary of the parameters monitored and the frequency of monitoring by the facility Iron Bridge, FL Water Hyacinth System Monitoring (EPA Design Manual, 1998) are presented in table 6 below. Based on this table we recommend the sampling frequency presented in table 7.

Table 6. Iron Bridge, FL Water Hyacinth System Monitoring

PARAMETERS	FREQUENCY
Influent flow	Daily
Air temperature	5 days/week
Wastewater temperature	5 days/week
pH	5 days/week
Conductivity	5 days/week
DO	5 days/week
Rainfall	Daily
Wind velocity	5 days/week
Wind direction	5 days/week
Chlorine	Twice/week
TKN	Twice/week
NH_4-N	Twice/week
NO_3-N	Twice/week
NO_2-N	Twice/week
TN	Twice/week
OP	Twice/week
TP	Twice/week
BOD_5	Twice/week
TSS	Twice/week
TDS	Once/week
Na	Once/week
K	Once/week
Fe	Once/week
Ca	Once/week
Mn	Once/week
Mg	Once/week
B	Once/week
Zn	Once/week
Cu	Once/week
Mb	Once/week
Cr	Once/week
Al	Once/week
Pb	Once/week
Hg	Once/week
Ni	Once/week
Cd	Once/week
SO_4	Once/week
Plant Constituents	As Needed
Harvested Biomass	As Needed
Stocked Biomass	As Needed
Standing Crop Biomass	Once/week
Weevils	Once/week
Sameodes	Once/week
Mosquitoes	Once/week
Encroaching Vegetation	Daily
Root Microinvertibrates	As Needed
Fungal Isolates	As Needed

Table 7: Parameters to be sampled and frequency of sampling.

PARAMETERS	FREQUENCY
Influent flow	Continuous
Outflow	Continuous
Air temperature	Twice/week
Graywater temperature	Twice/week
pH	Twice/week
Conductivity	Twice/week
DO	Twice/week
TKN	Twice/week
NH_4-N	Twice/week
NO_2 +NO_3-N	Twice/week
OP	Twice/week
TP	Twice/week
BOD_5	Twice/week
Chlorine	Twice/week
TSS	Twice/week
Total coliform	Twice/week
Faecal coliform	Twice/week
E.Coli	Twice/week
Mosquitoes	Periodic
Encroaching Vegetation	Monthly

CHAPTER 8

COST CONSIDERATION

The cost is of important consideration while constructing a wetland. There are several factors that depend on cost consideration such as: time of the year, topography of the site, site conditions, accessibility of equipments, economic scale and government regulations (http://www.epa.gov/ORD/NRMRL/pubs/600r04184/600r04184chap6.pdf). The cost effectiveness of the project depends on design, maintenance, construction costs and pollutant removal effectiveness (Landphair, 2000).

The capital costs of the current wetland project include land costs, construction costs and related site costs. The capital cost can be calculated using the equation (EPA Manual, 1999):

$$\mathbf{C = aP^b}$$

Where C is the estimated cost in dollars; P is the determinant variable (area or volume); and a and b are statistical coefficients determined from regression analysis. The exponent b represents the economics of scale factor. If $b < 1$, the unit cost decreases as size increases. When $b = 1$, the equation simplifies to a linear relationship and no economics-of-scale are present. If $b < 1$, then diseconomics of scale exist.

The design costs include site investigations, surveys, design and planning of the wetland. The contingency costs are the unexpected costs incurred during the construction of the project (http://www.epa.gov/ORD/NRMRL/pubs/600r04184/600r04184chap6.pdf). The design, permitting and contingency costs contribute to 25% of the base capital cost (EPA Manual, 1999). Erosion and sediment control represents only about 5 percent of the construction cost of basins and wetlands (Brown and Schueler. 1997b). Operation and maintenance costs include labor, materials energy and equipment required for proper operation of the constructed wetland (http://www.epa.gov/ORD/NRMRL/pubs/600r04184/600r04184chap6.pdf). Operation and maintenance costs are expressed as annual percentage of capital costs. Constructed wetland make up 3-6% of the capital costs (EPA Manual, 1999; Wiegand et al., 1986; Schueler, 1987; Southeastern Wisconsin Regional Planning Commission (SWRPC), 1991). Land cost must also be considered. Land costs are site specific and vary regionally (http://www.epa.gov/ORD/NRMRL/pubs/600r04184/600r04184chap6.pdf).

For constructed wetlands the equation is given as (EPA Manual, 1999 and Brown and Schueler. 1997b):

$$\mathbf{C = 18.5V^{0.70}}$$

Where V is the volume of the wetland in cubic feet. The estimated cost for the constructed wetland can be $176.00. The equation was based on data gathered from existing projects and assumptions that similar installations should cost about the same (http://www.epa.gov/ORD/NRMRL/pubs/600r04184/600r04184chap6.pdf). This value is just an estimate. But the actual cost involved in the project will be much greater than the amount mentioned here. Also the constructed wetland in the current project is a small one. The dimensions of the wetland are 4.9m*1.6m*0.8m.

CHAPTER 9

RECOMMENDATIONS AND CONCLUSIONS

RECOMMENDATIONS:

- The site selected for the constructed wetland can provide extra space for future expansion of the project.
- The effluent from the outlet structure can be reintroduced into the inlet zone of the wetland. This helps in increased dissolved oxygen concentrations at the inlet and decreases the influent constituent concentration.
- Different wetland plant species can be experimented to indicate the extent of pollutant removal in graywater.
- A facility to drain the wetland can be provided at particular locations. This would help in the harvesting of the constructed wetland vegetation.

CONCLUSIONS:

Constructed wetlands are being given much importance in the field of wastewater treatment. When properly designed and installed, constructed wetlands have proved to be successful in removing pollutants, providing an ecosystem similar to the natural wetlands. Constructed wetlands have also served as educational and recreational amenities.

In the current project an effort is being made to know how the wetlands can treat graywater. This project basically dealt with the preliminary design of a constructed wetland to treat graywater coming from the wash basin sinks in the Atmospheric Sciences Building, at the Colorado State University, Foothills Campus. The dimensions of the constructed wetland were determined to be 4.9m*1.6m*0.8m. The areal loading rate method was adopted to calculate the dimensions of the wetland. A forebay and a micropool must be installed at the inlet and the outlet zones respectively. A 90 degree V-notch will be installed at the outlet structure. The effluent from the outlet structure will be delivered to the sewer system through a bottom drain pipe.

There are three vegetative berms installed in the wetland - at the inlet, at the center of the wetland and along the micropool. V-shaped channels are used as the flow spreaders. The vegetation between in the wetlands are emergent.

The constructed wetland vegetation is composed of the common plant species found in Colorado. A geosynthetic clay liner was selected as the liner in order to protect the groundwater from contamination. The constructed wetland was designed only to treat the graywater and not the stormwater. The stormwater is diverted from entering the constructed wetland using a by-pass weir at the inlet.

This report summarizes the preliminary design details required for the installation of the wetland to treat the graywater coming out of the Atmospheric Sciences Building, at the Colorado State

University, Foothills Campus. It is hoped that the information provided in this report can be used to implement the project efficiently.

CHAPTER 10

ADDENDUM

This section is composed of the possibilities of future research work that can be carried out with constructed wetlands to treat graywater.

Wetlands have been a promising treatment facility in treating wastewaters originating from a variety of different sources. More emphasis is being given to constructed wetlands as they are low cost, low maintenance and low operating cost. Temperature affects the wetland performance. Wetlands perform efficiently in warm climates. Microbal activity is higher when temperatures are higher. Microbial mechanisms for the removal of nitrogen and organic carbon in wetland systems are known to be strongly temperature-dependent (Biederman, 1999). Also, the vegetation, hydrology and hydraulics of the wetland are influenced by temperature.

The performance of the wetland could be hindered in winter season because of the very low temperatures and formation of ice. As mentioned earlier the City of Fort collins receives an average snowfall of 51 inches per year, the average high temperature during the summer months is 85 degrees and in the winter months, it is 42 degrees, and therefore the temperature effects on the wetland have to be considered. Since the wetlands are shallow, the build up of ice can take up the entire volume. This in turn might freeze the wetland and hence hinder the treatment of graywater. In order to avoid the freezing of the wetland and improve the performance efficiency, proper measures are to be taken to ensure the proper functioning of the wetland in cold climates. However, the literature shows that the wetlands have been a success in cold climates.

Vegetation is an important concern in the winter seasons. In free water surface wetlands, the formation of ice and snow covers may damage the plants. The use of suitable submerged vegetation would be an alternative. Also, there might be oxygen deficiency because of the ice cover. An aeration system can be designed to provide sufficient oxygen to the wetland. Future research work can be done to design an appropriate aeration system for the wetland. An insulating mulch layer can be used to avoid freezing (http://www.baumpub.com/publications/cep/cep_features/cep_05mar_f1.htm).

Designing sub-surface wetlands can prove to be more promising than the free water surface wetlands in cold climates. In sub-surface wetlands, the damage to the vegetation due to ice cover is lower when compared to free water surface wetlands as the wetland plant species are below the ice cover. Providing a longer hydraulic detention time would increase the contact time between the vegetative species and microorganisms, which in turn helps in pollutant removal.

Burying the distribution system used to convey the graywater to the inlet of the wetland is an option to avoid freezing before reaching the wetland. Also, the wetland can be constructed on a slope. This will help in easy runoff of the snowmelt. An underdrain system can be designed to drain excessive water. Also, the underdrain system will help in draining the wetland regularly during harvesting of the vegetation and cleaning. Providing edges in the wetland will help in the accumulation of snow on top of the wetland (Denitrification in constructed wetlands in cold climate regions review.htm).

To ensure the performance of wetlands, and to determine the optimal size of the wetland, more than one wetland can be constructed with varying sizes and hydraulic retention time. Different depths and different species of vegetation can be experimented. In this case, the concept of the Degree of Freedom can be applied.

Degree of Freedom is that measure of variability which merely expresses the number of options available within a variable or space. In a system with N states the degree of freedom is N. In statistics of the N cells of a table of probabilities only N-1 can be arbitrarily filled, the last being determined by the requirement that probabilities must add to 1, hence the degree or freedom is N-1. The measure of uncertainty may be interpreted as a lograthmic measure of the degree of freedom logically or statistically available (http://pespmc1.vub.ac.be/ASC/DEGREE_FREED.html).

Considering the wetlands, if there are three of them constructed, two of the wetlands can prove to be promising according to the concept of degree of freedom. Of course this option can be executed if sufficient money is available for construction of more than one wetland. This option can be a future research project for the future students

Once the wetlands are constructed different plant species can be experimented and it can be examined which plant species are more promising and efficient in treating graywater.

Instead of having three sampling stations, more sampling stations can be installed, in order to check on the extent of pollutant removal from graywater. Samples can be collected more often and tested for various parameters. Depending on how much removal is achieved at each station, the wetland size can be reworked. It would be economical if the pollutant removal was achieved at a shorter length along the wetland. If the pollutant removal was not achieved before the graywater reaches the outlet structure the wetland will have to be expanded appropriately to achieve the required treatment of graywater.

If the currently designed wetland system proves to be a promising treatment facility, appropriate arrangements can be made in order to divert the treated graywater back into the Atmospheric Science Building and reused to flush toilets and in landscape irrigation. This would help in water conservation. However, in order to reuse the treated graywater permission from the State and Regulatory agencies. If partial treatment of graywater is achieved then some post treament process can be designed which would be promising and economical. This would serve as another research topic.

The reuse of graywater in winter climates is an important consideration. If the constructed wetland fails to function in the cold climate, then alternative treatment methods have to be considered. Else, the graywater has to be diverted to the wastewater treatment plant.

Depending on the quality of the graywater at the inlet of the wetland, it can be decieded if it can be used directly for landscape irrigation or fire protection in the winter climates. However, this option is not advisable as the graywater consists of pathogens which might be harmful for human health.

CHAPTER 11

STORMWATER MANAGEMENT

The problems associated with stormwater runoff include increased flooding magnitude and frequency, accelerated stream channel erosion, and water quality degradation and are becoming well known. In order to reduce these problems, extensive work is being done in the field of storm water management along with implementation of many practices that were not required 20 years ago.

My internship at JOHNSON, MIRMIRAN & THOMPSON (JMT) has given me an opportunity to work in the field of stormwater management.

I am working on the development of a town owned parking and multi-use lot, for the Town of Warsaw, Virginia. This design project is proposed for improvements in the Town of Warsaw, and specifically noted are the following considerations to be undertaken in connection with the parking lot development:

- Development of a two phase parking facility
- Reducing site runoff
- Future multi-use development adjacent to parking lot

Parking facility

The town goals for the parking facility include creation of off-street parking in the downtown area, removal of on street parking, increased sight distance on Main Street, site runoff reduction and the possibility of future multiuse development adjacent to the proposed parking lot. JMT has developed a preliminary parking lot layout for the town (Figure 1), and this layout provides all of the towns goals. By removing on-street parking, sight distance will be greatly improved. Although the existing lot is undeveloped, by developing the parking area using gravel, infiltration of runoff will be increased and the amount of runoff will be reduced prior to reaching Main Street. The lot, as designed, contains forty-six spaces, and is laid out as a continuous loop, with a one-way movement within the facility. This one way movement provides the needed circulation while maximizing the available land for parking.

The existing lot is approximately 1.7 acres in size, and is fairly level. Development of the site would not be difficult, as the majority of the lot to be developed in this phase has been cleared. There is an abandoned building located in the northeast corner of the property that would need to be demolished in order to develop the lot as designed.

Opportunities exist in the lot for enhanced bicycle and pedestrian access. Although the town will be redeveloping Main Street and the remainder of the lot as a separate phase or project, early planning for the parking facility should include the enhanced areas for bicycle and pedestrian movements. This project could include a pedestrian and bicycle access plan that unifies street-side sidewalks with other possible trails within the corridor in a manner that would provide a safe, functional and attractive plan for pedestrian and bicycle access.

Working on this project, I was able to look into the stormwater management in detail. The stormwater is proposed to be diverted into an infiltration pond (Surface Sand filter, Figure 2). The proposed site contours will divert the storm water into the infiltration basin located in the center of the parking lot as shown in Figure 3. The materials used for this sand filter were natural sand, underdrain gravel, underdrain piping and geotextile fabric.

When project construction is complete to a stage where no additional sediment from the project is expected to enter the basin, as determined by the engineer, the basin shall be cleaned out and restored to the original design elevations, the area stabilized and all temporary modifications to the stormwater management structure or other control structures removed.

Surface sand filter construction notes:

- The sand filter shall not be placed in service until the contributing drainage area has been stabilized. Heavy equipment and traffic shall be restricted from the proposed sand filter location to minimize compaction of the soil.
- All excavated material shall be placed away from the sand filter. When necessary, the sand filter walls shall be battered to maintain stability during construction. The bottom dimensions and stone/sand depth shall be as specified.
- Large tree roots shall be trimmed flush with the sand filter to prevent puncturing or tearing of the geotextile. The side walls of the sand filter shall be roughened where sheared and sealed during excavation.
- The bottom of the sand filter will be graded flat. No geotextile will be placed on the bottom of the sand filter.
- Two feet overlap shall be the minimum between rolls of geotextile.
- The stone capping shall be cleaned and free of all soil and fines.
- Over compaction must be avoided to ensure adequate filtration capacity. After the sand layer is placed, water settling is recommended.

Sand filter maintenance considerations:

- Filter barrier shall remain in place around the center of the pond along the outer edge of the pea gravel. Turf shall be fully established between the pea gravel center and the stone parking lot area.
- Mow grass as needed and remove any grass cutting from the pond area.

For temporary erosion and sediment control a silt fence and a riprap shall be provided.

A silt fence is defined as a temporary sediment barrier consisting of a synthetic filter fabric stretched across and attached to supporting posts and entrenched. The main purpose of a silt fence is to:

- Intercept and detain small amounts of sediment from disturbed areas during construction operations in order to prevent sediment from leaving the site.
- Decrease the velocity of sheet flows and low-to-moderate level channel flows.

Riprap is defined as a permanent, erosion-resistant ground cover of large, loose, angular stone with underlining filter fabric or grade granular stone/gravel.

The main purpose of a riprap is to:

- Protect the soil from the erosive forces of concentrated runoff.
- Slow the velocity of concentrated runoff while enhancing the potential for infiltration.
- To stabilize slopes with seepage problems and/or non-cohesive soils.

I was given the opportunity to review the project on the Relocation of Bridge 48, Moores Mill Road over Bynum Run, Harford County, Maryland. The study area limits were defined as the area within 450 West and 250 feet East of the bridge along Moores Mill Road, and 150 feet upstream and downstream of the roadway.

By reviewing this project I was able to go through the Clean Water Act, Section 404 which includes wetland delineation and forest characterization. This in turn helped me how to identify and delineate the extent of Clean Water Act, Section 404 jurisdictional wetlands and waters of the U.S., and to characterize the forest stands and identify the large or "significant" trees.

The Clean Water Act, Section 404 jurisdictional wetlands are defined as those areas satisfying the technical criteria contained in the Corps of Engineers Wetlands Delineation Manual, Technical Report Y-87-1, United States Waterway Experiment Station, Vicksburg, Mississippi, 1987 (Delineation Manual). Large or "significant" trees are defined as those trees with a measured diameter at breast height (dbh) of 30 inches or greater, and/or those trees with a dbh that is at least 75% the dbh of the state champion for that species.

A wetland delineation and forest characterization was conducted on August 16, 2000 along Moores Mill Road in the vicinity of Bynum Run. Bynum Run and its perennial tributaries were delineated as waters of the U.S. No adjacent wetlands were delineated.
Some forest land occurs within the project site, mostly on the south side of Moores Mill Road. As per Natural Resources Article 5-103 (Reforestation Law), reforestation on a 1:1 basis, on public land, is required if greater than one acre of forest impacts occur as aresult of this project.

A temporary crossing of Bynum Run during construction is likely. This in turn would affect the Bynum Run and its floodplain. If there will be any impact to the stream or flood plain a permit from the U.S. Army corps of Engineers and/or the Maryland Department of the Environment (MDE) is required prior to the initiation of any construction activities.

Wetland investigations of this type reflect the current state of variable conditions. Wetland delineations are often based on best professional judgment based on experience along with the information and techniques available. A determination of jurisdictional areas and their boundaries can only be conducted through a jurisdictional determination by the U.S. Army corps of Engineers and/or the Maryland Department of the Environment.

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APPENDIX 1

V-NOTCH DESIGN

Q = Cd*8/15*SQRT(2g)*(h^2.5)*TAN(θ/2)

θ(in degrees) = 10 Cd=0.581 (minimum value for all angles, Lenz, 1943) fluid mechanics with engg. Applications by R.L. Daugherty and A.C.Ingersoll

	H(ft)	Q (cfd)	
1	0.01	2.15667E-06	
2	0.02	1.22E-05	
3	0.03	3.36192E-05	
4	0.04	6.90135E-05	
5	0.05	0.000120562	
10	0.1	0.000682	
50	0.5	0.038124935	
100	1	0.2156672	
200	2	1.219997917	
300	3	3.361918931	
400	4	6.9013504	
414	4.14	7.521162166	
415	4.15	7.566662124	
416	**4.16**	**7.612326836**	**Qavg**
417	4.17	7.658156503	
418	4.18	7.704151321	
450	4.5	9.264359181	
489	4.89	11.40397477	
490	**4.9**	**11.46236675**	**Q peak**
491	4.91	11.52093776	
492	4.92	11.57968797	
493	4.93	11.63861757	

Q avg=	**7.63**	**cfd**
	0.21603	**m3/s**
Q peak	**11.44**	**cfd**
	0.324045	**m3/s**

Q = Cd*8/15*SQRT(2g)*(h^2.5)*TAN(θ/2)

θ(in degrees) = 20 Cd=0.581 (minimum value for all angles, Lenz, 1943)
fluid mechanics with engg. Applications by R.L. Daugherty and A.C.Ingersoll

	H(ft)	Q(cfd)	
1	0.01	4.36292E-06	
2	0.02	2.46804E-05	
3	0.03	6.80112E-05	
4	0.04	0.000139614	
5	0.05	0.000243895	
10	0.1	0.001379677	
50	0.5	0.077126305	
100	1	0.436292267	
150	1.5	1.202280111	
200	2	2.468041763	
250	2.5	4.311491526	
300	3	6.801123355	
310	3.1	7.382131034	
313	3.13	7.562029356	
314	**3.14**	**7.622573756**	**Qavg**
315	3.15	7.683408073	
350	3.5	9.998794117	
368	3.68	11.33436155	
369	3.69	11.41151829	
370	**3.7**	**11.48898931**	**Q peak**
371	3.71	11.56677504	
372	3.72	11.64487591	

Q avg=	**7.63**	**cfd**
	0.21603	**m3/s**
Q peak	**11.44**	**cfd**
	0.324045	**m3/s**

Q = Cd*8/15*SQRT(2g)*(h^2.5)*TAN(θ/2)

θ(in degrees) = 30 Cd=0.581 (minimum value for all angles, Lenz, 1943)
fluid mechanics with engg. Applications
by R.L. Daugherty and A.C.Ingersoll

	H(ft)	Q(cfd)	
1	0.01	6.64354E-06	
2	0.02	3.75815E-05	
3	0.03	0.000103563	
4	0.04	0.000212593	
5	0.05	0.000371385	
10	0.1	0.002100872	
100	1	0.664354133	
200	2	3.758154502	
250	2.5	6.565225732	
263	2.63	7.452277401	
264	2.64	7.523318681	
265	**2.65**	**7.594764753**	**Qavg**
266	2.66	7.666616384	
300	3	10.35625602	
311	3.11	11.3318447	
312	3.12	11.42315649	
313	**3.13**	**11.51490834**	**Q peak**
314	3.14	11.60710095	
315	3.15	11.69973502	

Q avg=	**7.63**	**cfd**
	0.21603	**m3/s**
Q peak	**11.44**	**cfd**
	0.324045	**m3/s**

Q = Cd*8/15*SQRT(2g)*(h^2.5)*TAN(θ/2)

θ(in degrees) = 45 Cd=0.581 (minimum value for all angles, Lenz, 1943)
fluid mechanics with engg. Applications by R.L. Daugherty and A.C.Ingersoll

	H(ft)	Q (cfd)	
1	0.01	1.02628E-05	
2	0.02	7.82274E-05	
3	0.03	0.000215569	
4	0.04	0.000442521	
5	0.05	0.000773052	
10	0.1	0.004373042	
50	0.5	0.244460474	
100	1	1.382877272	
150	1.5	3.810761654	
196	1.96	7.437445858	
197	1.97	7.532674553	
198	**1.98**	**7.628631107**	**Qavg**
199	1.99	7.725317366	
200	2	7.822735171	
231	2.31	11.21536956	
232	2.32	11.33714239	
233	**2.33**	**11.45970509**	**Q peak**
234	2.34	11.58305937	
235	2.35	11.70720692	

Q avg=	**7.63**	**cfd**
	0.21603	**m3/s**
Q peak	**11.44**	**cfd**
	0.324045	**m3/s**

Q = Cd*8/15*SQRT(2g)*(h^2.5)*TAN(θ/2)

θ(in degrees) = **60** Cd=0.581 (minimum value for all angles, Lenz, 1943)
TAN(60/2)= 0.577

fluid mechanics with engg. Applications by R.L. Daugherty and A.C.Ingersoll

	H(ft)	Q(cfd)	
1	0.01	0.035758613	
2	0.02	0.071517227	
3	0.03	0.10727584	
4	0.04	0.143034453	
5	0.05	0.178793067	
10	0.1	0.357586133	
100	1	3.575861333	
150	1.5	5.363792	
200	2	7.151722667	
212	2.12	7.580826027	
213	2.13	7.61658464	
214	**2.14**	**7.652343253**	**Qavg**
215	2.15	7.688101867	
216	2.16	7.72386048	
250	2.5	8.939653333	
300	3	10.727584	
318	3.18	11.37123904	
319	3.19	11.40699765	
320	**3.2**	**11.44275627**	**Q peak**
321	3.21	11.47851488	
322	3.22	11.51427349	

Q avg=	**7.63**	**cfd**
	0.21603	**m3/s**
Q peak	**11.44**	**cfd**
	0.324045	**m3/s**

Q = Cd*8/15*SQRT(2g)*(h^2.5)*TAN(θ/2)

θ(in degrees) = 90 Cd=0.581 (minimum value for all angles, Lenz, 1943)
fluid mechanics with engg. Applications
by R.L. Daugherty and A.C.Ingersoll

	H(ft)	Q(cfd)					
1	0.01	2.47893E-05	**Q avg=**	**7.63**	**cfd**	**0.15*Qavg=**	**1.15 cfd**
2	0.02	0.00014023		**0.21603**	**m3/s**		
3	0.03	0.000386427					
4	0.04	0.000793259	**Q peak**	**11.44**	**cfd**	**0.15*Qpeak=**	**1.72 cfd**
5	0.05	0.001385766		**0.324045**	**m3/s**		
10	0.1	0.007839076					
100	1	2.478933333					
146	1.46	6.384795428					
146.2	1.462	6.406683635					
146.3	1.463	6.417644597					
146.5	1.465	6.439600257					
146.7	1.467	6.461600923					
146.8	1.468	6.472618143					
146.9	**1.469**	**6.483646627**	**Q(-)-Q avg**				
147	1.47	6.494686377					
156	1.56	7.534880053					
156.6	1.566	7.607539949					
156.7	1.567	7.619690626					
156.8	**1.568**	**7.631852939**	**Qavg**				
156.9	1.569	7.644026893					
165	1.65	8.669113877					
165.6	1.656	8.74813907					
165.8	1.658	8.774576463					
165.9	**1.659**	**8.787813113**	**Q(+)+Q avg**				
172	1.72	9.618026395					
172.2	1.722	9.646010162					
172.4	1.724	9.674042724					
172.6	1.726	9.702124108					
172.7	**1.727**	**9.716183118**	**Q(-)-Qpeak**				
172.8	1.728	9.730254344					
172.9	1.729	9.744337791					

APPENDIX 2

CSU Foothills Campus Water Study
Wetland Design - Atmospheric Science
Greywater Wetland
Preliminary Design

Avg. Flow =	1.5	gal/cap/day of greywater
	38	people
	57	gal/day of greywater
	0.21603	m3/day
Peak Factor =	**1.5**	
Peak Flow=	86	MGD
	0.324045	m3/day
BODavg=	129	mg/L
BODmaxload=	100	mg/L
TSSavg=	79.2	mg/L
TSSmaxload=	30	mg/L

ALR Analysis

Areal Loading Rate, ALR = QCo/Aw

ALR - BOD	40	kg/ha-day
ALR - TSS	30	kg/ha-day

BOD Based ALR			**TSS Based ALR**		
Aw - average Q	0.000695	Ha	Aw - average Q	0.00057032	ha
	74.78551	cu-ft		61.3624677	cu-ft
Aw - peak Q	0.00081	Ha	Aw - peak Q	0.00032405	ha
	87.1626	cu-ft		34.8650385	cu-ft
Selected Area =	0.00081	Ha			
	87.1626	cu-ft			

HRT

Hydraulic Loading Rate = t=Vw*ε/Qave

ε =	0.75	h=	0.6	Zone 1&3 Vegetated Zones
ε =	1	h=	1.2	Zone 2 Free Water Surface

Weighted Avg=	0.833333			0.8			
t - average Q	25	Days					
t - peak Q	16.66667	Days					

Minimum HRT: Zone 1 (2 days)+ Zone 2 (2 days) + Zone 3 (2 days) — 6 days for max flow; 9 days for average flow

Recalculated Aw=(t*Q)/(h*ε)

Aw - average Q	0.000292	ha
	31.37853	cu-ft
Aw - peak Q	0.000292	ha
	31.37853	cu-ft

Wetlands Area=	**0.00081**	**Ha**				
	87.1626	**cu-ft**				
Length=	**16.17058**	**Ft**	**4.928794**	**m**	**L:W Ratio =**	**3:1**
Width=	**5.390195**	**Ft**	**1.642931**	**m**		
Depth=	**0.8**	**M**	**average**			
Retention Time	**11.44047**	**Days**				

Conversion Factors

1 mile =	5,280	ft
1 ft =	12	in
1 cu-ft =	7.4815	gallons
1 acre =	43,560	cu-ft
1 gallon=	3.79	Liters
1 kg=	1,000,000	mg
1 lb=	0.4536	kg
1 MG=	1,000,000	gallons
1 liters =	0.0010	cubic meters (m^3)
1 ha =	10,000	square meters (m^2)
1 ha =	2.47	acres