Role of Plants in Constructed Wetland System

Dr. Shalini Saxena

***Abstract*— Wetlands, either constructed or natural, offer a cheaper and low-cost alternative technology for wastewater treatment. A constructed wetland system that is specifically engineered for water quality improvement as a primary purpose is termed as a 'Constructed Wetland Treatment System' (CWTS). In the past, many such systems were constructed to treat low volumes of wastewater loaded with easily degradable organic matter for isolated populations in urban areas. However, widespread demand for improved receiving water quality, and water reclamation and reuse, is currently the driving force for the implementation of CWTS all over the world. Recent concerns over wetland losses have generated a need for the creation of wetlands, which are intended to emulate the functions and values of natural wetlands that have been destroyed. Natural characteristics are applied to CWTS with emergent macrophyte stands that duplicate the physical, chemical and biological processes of natural wetland systems. The number of CWTS in use has very much increased in the past few years. The use of constructed wetlands is gaining rapid interest. Most of these systems cater for tertiary treatment from towns and cities. They are larger in size, usually using surface-flow system to remove low concentration of nutrient (N and P) and suspended solids. However, in some countries, these constructed wetland treatment systems are usually used to provide secondary treatment of domestic sewage for village populations. These constructed wetland systems have been seen as an economically attractive, energy-efficient way of providing high standards of wastewater treatment.**

Typically, wetlands are constructed for one or more of four primary purposes: creation of habitat to compensate for natural wetlands converted for agriculture and urban development, water quality improvement, flood control, and production of food and fiber (constructed aquaculture wetlands).

***Index Terms*— CWTS, macrophyte,surface flow, domestic sewage, aquaculture wetlands**

I. INTRODUCTION

Constructed wetland treatment systems are a new technology for India. It is a cheaper alternative for wastewater treatment using local resources. Aesthetically, it is a more landscaped looking wetland site compared to the conventional wastewater treatment plants. This system promotes sustainable use of local resources, which is a more environment friendly biological wastewater treatment system. Constructed wetlands can be created at lower costs than other treatment options, with low-technology methods where no new or complex technological tools are needed. The system relies on renewable energy sources such as solar and kinetic energy, and wetland plants and micro-organisms, which are the active agents in the treatment processes. The system can tolerate both great and small volumes of water and varying contaminant levels. These include municipal and domestic wastewater, urban storm runoff, agricultural wastewater, industrial effluents and polluted surface waters in rivers and lakes. The system could be promoted to various potential users for water quality improvement and pollutant removal. These potential users include the tourism industry, governmental departments, private entrepreneurs, private residences, aquaculture industries and agro-industries.

Utilisation of local products and labour, helps to reduce the operation and maintenance costs of the applied industries. Less energy and raw materials are needed, with periodic on-site labour, rather than continuous full time attention. This system indirectly will contribute greatly in the reduction of use of natural resources in conventional treatment plants, and wastewater discharges to natural waterways are also reduced.

The constructed wetland system also could be used to clean polluted rivers and other water bodies. This derived technology can eventually be used to rehabilitate grossly polluted rivers in the country. The constructed wetland treatment system is widely applied for various functions. These functions include primary settled and secondary treated sewage treatment, tertiary effluent polishing and disinfecting, urban and rural runoff management, toxicant management, landfill and mining leachate treatment, sludge management, industrial effluent treatment, enhancement of instream nutrient assimilation, nutrient removal via biomass production and export, and groundwater recharge.

The primary purpose of constructed wetland treatment systems is to treat various kinds of wastewater (municipal, industrial, agricultural and stormwater). However the system usually serves other purposes as well. A wetland can serve as a wildlife sanctuary and provide a habitat for wetland animals. The wetland system can also be aesthetically pleasing and serve as an attractive destination for tourists and local urban dwellers. It can also serve as a public attraction sanctuary for visitors to explore its environmental and educational possibilities. It appeals to different groups varying from engineers to those involved in wastewater facilities as well as environmentalists and people concerned with recreation. This constructed wetland treatment system also provides a research and training ground for young scientists in this new research and education arena.

II. NATURAL WETLANDS VS CONSTRUCTED WETLANDS

Constructed wetlands, in contrast to natural wetlands, are man-made systems or engineered wetlands that are designed, built and operated to emulate functions of natural wetlands for human desires and needs. It is created from a non-wetland ecosystem or a former terrestrial environment, mainly for the

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Dr. Shalini Saxena, Govt.M.L.B. College Bhopal, India

purpose of contaminant or pollutant removal from wastewater (Hammer, 1994).These constructed wastewater treatments may include swamps and marshes. Most of the constructed wetland systems are marshes. Marshes are shallow water regions dominated by emergent herbaceous vegetation including cattails, bulrushes, rushes and reeds.

III. METHODOLOGY TO PREPARE VARIOUS TYPES OF CONSTRUCTED WETLAND SYSTEMS

Constructed wetland systems are classified into two general types: the Horizontal Flow System (HFS) and the Vertical Flow System (VFS). HFS has two general types: Surface Flow (SF) and Sub-surface Flow (SSF) systems. It is called HFS because wastewater is fed at the inlet and flows horizontally through the bed to the outlet. VFS are fed intermittently and drains vertically through the bed via a network of drainage pipes.

Surface Flow (SF) - The use of SF systems is extensive in North America. These systems are used mainly for municipal wastewater treatment with large wastewater flows for nutrient polishing. The SF system tends to be rather large in size with only a few smaller systems in use.

The majority of constructed wetland treatment systems are Surface-Flow or Free-Water surface (SF) systems. These types utilise influent waters that flow across a basin or a channel that supports a variety of vegetation, and water is visible at a relatively shallow depth above the surface of the substrate materials. Substrates are generally native soils and clay or impervious geotechnical materials that prevent seepage (Reed, et al., 1995). Inlet devices are installed to maximise sheetflow of wastewater through the wetland, to the outflow channel. Typically, bed depth is about 0.4 m.

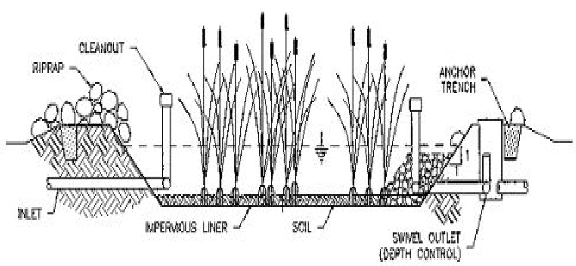

FIG 1 SURFACE FLOW CONSTRUCTED WETLAND

Sub-surface Flow (SSF) system - The SSF system includes soil based technology which is predominantly used in Northern Europe and the vegetated gravel beds are found in Europe, Australia, South Africa and almost all over the world. In a vegetated Sub-surface Flow (SSF) system, water flows from one end to the other end through permeable substrates which is made of mixture of soil and gravel or crusher rock. The substrate will support the growth of rooted emergent vegetation. It is also called "Root-Zone Method" or "Rock-Reed-Filter" or "Emergent Vegetation Bed System". The media depth is about 0.6 m deep and the bottom is a clay layer to prevent seepage. Media size for most gravel substrate ranged from 5 to 230 mm with 13 to 76 mm being typical. The bottom of the bed is sloped to minimise water that flows overland. Wastewater flows by gravity horizontally through the root zone of the vegetation about 100-150 mm below the gravel surface. Many macro and micro-organisms inhabit the substrates. Free water is not visible. The inlet zone has a buried perforated pipe to distribute maximum flow horizontally through the treatment zone. Treated water is collected at outlets at the base of the media, typically 0.3 to 0.6 m below bed surface.

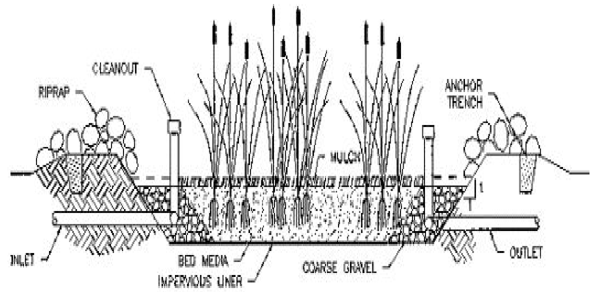

Figure 2: Typical configuration of a sub-surface flow Constructed wetland

IV. METHODOLOGY OF CONSTRUCTED WETLAND TREATMENT SYSTEMS FOR WASTE WATER TREATMENT

The creation of a constructed wetland treatment system can be divided into a wetland construction and vegetation establishment stage. Wetland construction includes pre-construction activities such as land clearing and site preparation, followed by construction of a wetland landform and installation of water control structures. In the stage of site clearing and grubbing, the site is cleared and existing vegetation is removed to allow construction of wetland cells. All tree root stumps and rubble below ground should be removed. Some endemic species with conservation values should be transferred off site for ex-conservation or protected intact on the site. For landforming, tractors are used to remove and stockpile topsoils from the created wetland to be reused. General contours of the wetland are graded, followed by the construction of wetland cell berms by compacting soil and installing of liners. Deep zones and islands will be created. Final site grading consists of leveling the wetland cell bottom to optimise the spreading and sheetflow of wastewaters in the completed wetland. The wetland cells are flooded to a 'wet' condition for planting. Wetland plants are transferred to the site and planted manually. After plants are established, water levels are gradually increased to normal water levels, and wetlands are completely created.

V. ROLES OF WETLANDS PLANTS IN WASTEWATER TREATMENT

In general, the most significant functions of wetland plants (emergents) in relation to water purification are the physical effects brought by the presence of the plants. The plants provide a huge surface area for attachment and growth of microbes. The physical components of the plants stabilise the surface of the beds, slow down the water flow thus assist in sediment settling and trapping process and finally increasing water transparency.

Wetland plants play a vital role in the removal and retention of nutrients and help in preventing the eutrophication of wetlands. A range of wetland plants has shown their ability to assist in the breakdown of wastewater. The Common Reed Phragmites karka and Cattail Typha angustifolia are good examples of marsh species that can effectively uptake nutrients. These plants have a large biomass both above (leaves) and below (underground stem and roots) the surface of the substrate. The sub-surface plant tissues grow horizontally and vertically, and create an extensive matrix, which binds the soil particles and creates a large surface area for the uptake of nutrients and ions.

Hollow vessels in the plant tissues enable oxygen to be transported from the leaves to the root zone and to the surrounding soil (Armstrong et al., 1990; Brix and Schierup, 1990). This enables the active microbial aerobic decomposition process and the uptake of pollutants from the water system to take place.

The roles of wetland plants in constructed wetland systems can be divided into 6 categories:

Physical - Macrophytes stablise the surface of plant beds, provide good conditions for physical filtration, and provide a huge surface area for attached microbial growth. Growth of macrophytes reduces current velocity, allowing for sedimentation and increase in contact time between effluent and plant surface area, thus, to an increase in the removal of Nitrogen.

Soil hydraulic conductivity - Soil hydraulic conductivity is improved in an emergent plant bed system. Turnover of root mass creates macropores in a constructed wetland soil system allowing for greater percolation of water, thus increasing effluent/plant interactions.

Organic compound release - Plants have been shown to release a wide variety of organic compounds through their root systems, at rates up to 25% of the total photosynthetically fixed carbon. This carbon release may act as a source of food for denitrifying microbes (Brix, 1997). Decomposing plant biomass also provides a durable, readily available carbon source for the microbial populations.

Microbial growth - Macrophytes have above and below ground biomass to provide a large surface area for growth of microbial biofilms. These biofilms are responsible for a majority of the microbial processes in a constructed wetland system,

Plants create and maintain the litter/humus layer that may be likened to a thin biofilm. As plants grow and die, leaves and stems falling to the surface of the substrate create multiple layers of organic debris (the litter/humus component). This accumulation of partially decomposed biomass creates highly porous substrate layers that provide a substantial amount of attachment surface for microbial organisms. The water quality improvement function in constructed and natural wetlands is related to and dependent upon the high conductivity of this litter/humus layer and the large surface area for microbial attachment also needs to be maintained at an optimum rate to maintain treatment efficiency.

The Common Reed (Phragmites spp.) and Cattail (Typha spp.) are good examples of emergent species used in constructed wetland treatment systems. Plant selection is quite similar for SF and SSF constructed wetlands. Emergent wetland plants grow best in both systems. These emergent plants play a vital role in the removal and retention of nutrients in a constructed wetland. Although emergent macrophytes are less efficient at lowering Nitrogen and Phosphorus contents by direct uptake due to their lower growth rates (compared to floating and submerged plants), their ability to uptake Nitrogen and Phosphorus from sediment sources through rhizomes is higher than from the water.

Design and principles of constructed wetland systems

The principal design criteria for a constructed wetland system includes substrate types, pollutant loading rate and retention time. Some design criteria are discussed in detail as below.

Choice of wetland plant species - The selected wetland plants are preferred because they have a rapid and relatively constant growth rate. In a tropical system, wetland plants have a higher growth rate. These wetland plants are easily propagated by means of runners and by bits of mats breaking off and drifting to new areas. This will help in increasing the capacity of pollutant absorption by the plants. The plants should also be able to tolerate waterlogged-anoxic and hyper-eutrophic conditions.

The plant species should be local species and widely distributed in the country. Use of exotic plants in constructed wetland systems should be avoided as they are highly invasive and difficult to control. The plant should be a perennial with a life cycle of more than one year or two growing seasons to ensure the sustainability of the constructed wetland system. Wetland plants with aesthetic appeal will provide a landscape-pleasing environment.

Substrates - Substrates may remove wastewater constituents by ion exchange/non-specific adsorption, specific adsorption/precipitation and complexation.

The choice of substrate is determined in terms of their hydraulic permeability and their capacity to absorb nutrients and pollutants. The substrate must provide a suitable medium for successful plant growth and allow even infiltration and movement of wastewater. Poor hydraulic conductivity will result in surface flow and channeling of wastewater, severely reducing the effectiveness of the system.

A successful operation requires a hydraulic conductance of approximately 10-3 to 10-4 m -1 s-1. The chemical composition of the substrate will also affect the efficiency of the system. Soils with low nutrient content will encourage direct uptake of nutrients from the wastewater by plants. Substrate with high Al or Fe content will be most effective at lowering Phosphate concentrations in the influent. Gravels are washed to reduce clogging (increase void spaces) for better filtration. The reed system on gravel reached better nitrification rates, while denitrification was higher in the soil-based reed system (Markantonatos et al., 1996).

A mixture of organic clay soils, sand, gravels and crushed stones could be used to provide support for plant growth. These substrates are ideal reactive surfaces for ion complexation and microbial attachment, also provide a sufficiently high hydraulic conductivity to avoid short-circuiting in the system

Area of reed bed - Most wastewater treatment wetlands have been designed for minimum size and cost to provide the required level of pollutant removal. However, operation and maintenance costs may be high. The creation of a maximum effective treatment area will reduce the short-circuiting problem. Generally, horizontal flow wastewater treatment systems should have a 3-4: 1 length to width ratio and be rectangular in shape if minimal treatment area is available. A long length-width ratio is required to ensure plug flow hydraulics (Miller and Black, 1985).

The required surface area for a sub-surface flow system is calculated according to an empirical formula for the reduction of BOD5 in sewage effluent.

The value of K = 5.2 was derived for a 0.6 m deep bed and operating at a minimum temperature of 80C. For less biodegradable wastewater, K values of up to 15 may be appropriate. Using this formula, a minimum area of 2.2 m2 pe-1 is obtained for the treatment of domestic sewage. In practice, most design systems operate on the basis of 3-5 m2 pe-1.

Ah = KQd (In C0 - In Ct)

Where Ah = surface area of bed, m2

K = rate constant, m d-1

Qd= average daily flow rate of wastewater (m3 d-1)

C0 = average daily BOD5 of the influent (mg l-1)

Ct = required average daily BOD5 of the effluent (mg l-1)*11*

Nature, loading and distribution of effluent - The long-term efficiency of an emergent bed system is improved if the effluent is pre-treated prior to discharge to the active bed. Suspended particles are settled during storage in a settlement tank or a pond for 24 hours. The BOD of the primary effluent may be reduced by 40%. The removal of Nitrogen and Phosphorus for secondary wastewater is higher.

The flow of wastewater through the emergent bed system is slow, giving a long retention time, therefore the flow must be regulated so that retention times are sufficiently long for pollutant removal to be efficient. A higher reduction efficiency for mass balances of N and P could be achieved by Phragmites if water retention time is more than 5 days. Shorter retention times do not provide adequate time for pollutant degradation to occur. Longer retention times can lead to stagnant and anaerobic conditions. Evapotranspiration can significantly increase the retention time.

Constructed wetland treatment mechanisms

Wetlands have been found to be effective in treating BOD, TSS, N and P as well as for reducing metals, organic pollutants and pathogens. The principal pollutant removal mechanisms in constructed wetlands include biological processes such as microbial metabolic activity and plant uptake as well as physico-chemical processes such as sedimentation, adsorption and precipitation at the water-sediment, root-sediment and plant-water interfaces (Reddy and DeBusk, 1987).

Microbial degradation plays a dominant role in the removal of soluble/colloidal biodegradable organic matter in wastewater. Biodegradation occurs when dissolved organic matter is carried into the biofilms that attached on submerged plant stems, root systems and surrounding soil or media by diffusion process. Suspended solids are removed by filtration and gravitational settlement.

A pollutant may be removed as a result of more than one process at work.

Nitrogen removal mechanisms - There are sufficient studies to indicate some roles being played by wetland plants in Nitrogen removal but the significance of plant uptake vis-à-vis nitrification/denitrification is still being questioned. Nitrogen (N) can exist in various forms, namely Ammoniacal Nitrogen (NH3 and NH4+), organic Nitrogen and oxidised Nitrogen (NO2- and NO3-). The removal of Nitrogen is achieved through nitrification/denitrification, volatilisation of Ammonia (NH3) storage in detritus and sediment, and uptake by wetland plants and storage in plant biomass (Brix, 1993). A majority of Nitrogen removal occurs through either plant uptake or denitrification. Nitrogen uptake is significant if plants are harvested and biomass is removed from the system. At the root-soil interface, atmospheric oxygen diffuses into the rhizosphere through the leaves, stems, rhizomes and roots of the wetland plants thus creating an aerobic layer similar to those that exists in the media-water or media-air interface. Nitrogen transformation takes place in the oxidised and reduced layers of media, the root-media interface and the below ground portion of the emergent plants. Ammonification takes place where Organic N is mineralised to NH4+-N in both oxidised and reduced layers. The oxidised layer and the submerged portions of plants are important sites for nitrification in which Ammoniacal Nitrogen (AN) is converted to nitrite N (NO2-N) by the Nitrosomonas bacteria and eventually to nitrate N (NO3-N) by the Nitrobacter bacteria which is either taken up by the plants or diffuses into the reduced zone where it is converted to N2 and N2O by the denitrification process .

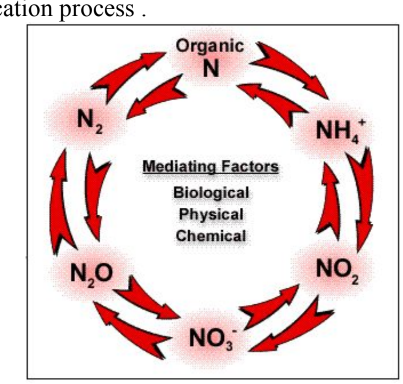

FIGURE 3: NITROGEN CYCLE

Denitrification is the permanent removal of Nitrogen from the system, however the process is limited by a number of factors, such as temperature, pH, redox potential, carbon availability and nitrate availability (Johnston, 1991). The annual denitrification rate of a surface-flow wetland could be determined using a Nitrogen mass-balance approach, accounting for measured influx and efflux of Nitrogen, measured uptake of Nitrogen by plants, and sediment, and estimated NH3 volatilisation (Frankenbach and Meyer, 1999).

The extent of Nitrogen removal depends on the design of the system and the form and amount of Nitrogen present in the wastewater. If influent Nitrogen content is low, wetland plants will compete directly with nitrifying and denitrifying bacteria for NH4+ and NO3-, while in high Nitrogen content, particularly Ammonia, this will stimulate nitrifying and denitrifying activity (Good and Patrick, 1987).

Phosphorus removal mechanisms - Phosphorus is present in wastewaters as Orthophosphate, Dehydrated Orthophosphate (Polyphosphate) and Organic Phosphorus. The conversion of most Phosphorus to the Orthophosphate forms (H2PO4-, Po42-, PO43-) is caused by biological oxidation.

Most of the Phosphorus component may fix within the soil media. Phosphate removal is achieved by physical-chemical processes, by adsorption, complexation and precipitation

reactions involving Calcium (Ca), Iron (Fe) and Aluminium (Al). The capacity of wetland systems to absorb Phosphorus is positively correlated with the sediment concentration of extractable Amorphous Aluminium and Iron (Fe).
Although plant uptake may be substantial, the sorption of Phosphorus (Orthophosphate P) by anaerobic reducing sediments appears to be the most important process. The removal of Phosphorus is more dependent on biomass uptake in constructed wetland systems with subsequent harvesting.

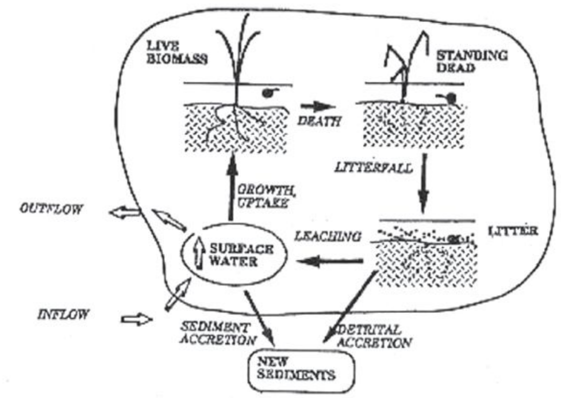

FIG 4 :PHOSPHORUS CYCLE

Plant uptake - Nitrogen will be taken up by macrophytes in a mineralised state and incorporated it into plant biomass. Accumulated Nitrogen is released into the system during a die-back period. Plant uptake is not a measure of net removal. This is because dead plant biomass will decompose to detritus and litter in the life cycle, and some of this Nitrogen will leach and be released into the sediment. Johnston (1991) shows only 26-55% of annual N and P uptake is retained in above-ground tissue, the balance is lost to leaching and litter fall.

Metals - Metals such as Zinc and Copper occur in soluble or particulate associated forms and the distribution in these forms are determined by physico-chemical processes such as adsorption, precipitation, complexation, sedimentation, erosion and diffusion. Metals accumulate in a bed matrix through adsorption and complexation with organic material. Metals are also reduced through direct uptake by wetland plants. However over-accumulation may kill the plants.

Pathogens - Pathogens are removed mainly by sedimentation, filtration and absorption by biomass and by natural die-off and predation.

Other pollutant removal mechanisms - Evapotranspiration is one of the mechanisms for pollutant removal. Atmospheric water losses from a wetland that occurs from the water and soil is termed as evaporation and from emergent portions of plants is termed as transpiration. The combination of both processes is termed as evapotranspiration.
Daily transpiration is positively related to mineral adsorption and daily transpiration could be used as an index of the water purification capability of plants.
Precipitation and evapotranspiration influence the water flow through a wetland system. Evapotranspiration slows water flow and increases contact times, whereas rainfall, which has the opposite effect, will cause dilution and increased flow.
Precipitation and evaporation are likely to have minimal effects on constructed wetlands in most areas. If the wetland type is primarily shallow open water, precipitation/evaporation ratios fairly approximate water balances. However, in large, dense stands of tall plants, transpiration losses from photosynthetically active plants become significant.

CONCLUSION & RESULTS

Monitoring and maintenance of the wetland areas is a key issue in maintaining wetland functioning. Wetland monitoring is required to obtain sufficient data to determine the wetland performance in fulfilling the objectives. Wetland maintenance is required to manage macrophytes and desirable species, to remove invading weeds, to remove sediment from the wetlands, and to remove litter from the wetlands Effective wetland performance depends on adequate pretreatment, conservative constituent and Nutrient removal depends upon seasons; hence it depends upon the temperature. The nutrient removal was higher in growing season rather than colder months. Planted microcosm outperformed unplanted microcosms, which proves the importance of macrophysics in a wetland. These plants help in nutrient cycling and microbial processes, which are major processes involved in nutrient removal. The average reduction of nitrate and nitrite concentration in the first year was 35.6 % and 49.2% in the flowing year. The significant difference in the net reductions was due to increase in plant cover, which helped in increasing HRT of the wetland and with increase in time, accumulation of the organic material increase the rate of denitrification. Total phosphorus (TP) reduction for the first year was 74.4% and the reduction decreased in the second water year to 40.6% for an overall reduction of 59.2%.The average overall reduction of SRP (soluble reactive phosphorus) was 54.4% and 59.4% in the first and the second year respectively.
Over the two year period, the wetland showed effective reductions in the nitrate and phosphorous levels. The wetland design did prove to a sink for nutrients, even during the high nutrient loading times of the year. The phosphorus reduction decreased in the second year, because with time, sediment and litter in the wetland becomes saturated with phosphorus. The wetland has to be design according to the type of nutrient it is designed to remove.

REFERENCES

[1] Andersson,J.L, Bastviken, S.K., and Tonderski, K.S. 2005. Free water surface wetlands for wastewater treatment in Sweden: nitrogen and phosphorus removal. Water science and technology. 51(9), 31-46
[2] Bastviken, S. 2006. Nitrogen removal in treatment wetlands –Factors influencing spatial and temporalvariations. Dissertation No 1041. Linköping University, Sweden
[3] Davis, L. 1993. A handbook for constructed wetlands. Available at :http://www.epa.gov/owow/wetlands/pdf/hand.pdf
[4] DeBusk. W.F. 1999. Wastewater Treatment Wetlands: Applications and Treatment Efficiency. Availableat: http://edis.ifas.ufl.edu/SS294

[5] Fink, D.F., W.J.Mitsch. 2004. Seasonal and storm event nutrient removal by a created wetland in anagricultural watershed. Ecological Engineering, 23(4-5); 313-325

[6] Fisher, J. and Acreman, M.C. 2004. Wetland nutrient removal: a review of the evidence. Hydrology andearth systems sciences. 8(4), 673-685

[7] Maine, M.A., N. Sune, H.Hadad, G. Sanchez, C. Benetto. 2006. Nutrient and metal removal in aconstructed wetland for wastewater treatment from a metallurgic industry. EcologicalEngineering. 26(4); 341-347

[8] Picard, C.R, Fraser, L.H. and Steer, D. 2005. The interacting effects of temperature and plant communitytype on nutrient removal in wetland microcosms. Bioresource technology. 96(9),1039 – 1047

[9] Sakadevan, K., H.J. Bavor.1999. Nutrient removal mechanisms in constructed wetlands and sustainablewater management. Water Science and Technology. 40(2); 121-128

[10] Sundaravadivel, M. and Vigneswaran,S. 2001. Constructed Wetlands for Wastewater treatment. Critical Reviews in Environmental Science and Technology, 31(4):351–409

[11] USEPA. 2006. Unites sates environmental protection agency. Available at: http://www.epa.gov/wetlands/

[12] Verhoeven, J.T. and Meuleman, F.M. 1999. Wetlands for wastewater treatment: Opportunities andlimitations. Ecological engineering. 12, 5-12

[13] Internet references:Constructed wetlands 2002. Alternative Systems Plan Review and Design Course Available at: http://www.cet.nau.edu/Projects/WDP/resources/treatmentsyst/Wetland.htm

[14] Magmedov, V. 2002. Constructed wetlands for low cost treatment. . Available at http://www.constructedwetlands.org/cw/index.cfm

[15] Nitrogen cycles project. Illinois State Water Survey. Available at: http://www.sws.uiuc.edu/nitro/biogeo.asp