Nutrient removal from wastewater by wetland systems

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Abstract: For past so many years wetlands have served functions like providing habitat for aquatic and terrestrial plants and animals, for recreational activities and for treatment of polluted water. Both natural and constructed wetlands gave been used for treatment for wastewater from sewage, septic tanks, agricultural activities, industries, landfills and highways, etc. Treatment of wastewater in a wetland includes process like sedimentation, filtration, removal of BOD and COD and removal of nutrients. The removal of nutrient includes removal of nitrogen and phosphorus. Removal of nitrogen takes place by the process of nitrification and denitrification, which results in removal of nitrogen in the form of N_2 gas. Phosphorus is removed by process of adsorption to the ions of metals like Fe, Al, Mg, etc. The removal of nutrients in wetlands is effected by factors like inflow rate, outflow rate, pollutant loading rate, hydraulic retention time (HRT), hydraulic loading rate, climatic conditions, temperature, pH, oxygen availability, wetland design components – substrate, vegetation and living organisms. Case studies presented in the paper provide an insight on the efficiency of contracted wetlands to remove the nutrients and changes in the efficiency of nutrient removal by the change in the factors affecting it.

Keywords: Constructed wetlands, nutrient removal, nitrogen, phosphorus

Introduction

According to USEPA 2006 the term wetland is defined as "those areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs and similar areas."

Wetlands are the areas where water table is at or near the land surface and rocks and gravel are submerged in the water during some time or the whole growing season. Hydrophytes (water tolerant plant species) are adapted to grow in the hydric soils of the wetlands. The types of plant and animal communities surviving in the wetland and development of the soil depend upon the saturation state of the soil in the wetland.

Wetlands exist naturally in our ecosystem, but wetlands can also be constructed to simulate the processes and functions of natural wetlands. Natural wetlands are transitional areas between the terrestrial and aquatic systems (Sundaravadivel 2001). USEPA categorizes four types of natural wetlands: marshes, swamps, bogs and fens.

- Marshes are lands continually saturated with water and having optimum conditions for growth of plants. Marshes can be of two types depending on the location– Tidal and Non-Tidal. Non-tidal marshes are more common in North America.
- Swamps are wetlands that have standing water or saturated soil condition depending upon the season. Swamps are generally dominated by woody plants. They can be classified in to forested swamps and shrub swamps depending upon the type of vegetation.
- Bogs are fresh water wetlands with spongy peat deposit and water surface covered with sphagnum moss. Bogs have acidic water and low nutrient levels and hence are not suitable for plant growth. Depending upon the location, bogs can be of two types: Northern bogs and Pocosins.
- Fens are peat forming wetlands but are less acidic and have higher nutrient levels than bogs. Fens have much larger plant and animal communities.

Some of the important functions of the wetlands include providing habitat for aquatic and terrestrial plants and animals, nesting and resting sites for migrating birds. Wetlands can also control floods by absorbing and slowing down floodwaters. Wetlands have a recreational value as they are used for fishing, canoeing, hiking and bird watching. Wetlands can absorb nutrient, sediments and pollutants and this property can be used to treat wastewater by the wetland system. Wetlands can be constructed to fulfill any of the above uses of the wetlands; for instance, constructed habitat wetlands, constructed flood control wetlands, constructed aquaculture wetlands and constructed wastewater treatment wetlands Sundaravadivel 2001). Constructed wetlands are more efficient than natural wetlands because they are designed for optimum performance of the particular function (they are designed for). The objective of this paper is to study the removal of nutrients from wastewater by constructed treatment wetland systems.

Treatment of wastewater with wetland systems has its advantages and disadvantages. Some of the advantages include: low energy input because solar energy is required for plant and animals communities to thrive in the wetlands, low operational maintenance, relatively more tolerant to varying pollutant load as compared to a wastewater treatment plant, constructed wetlands have no design life period as opposed to a treatment plant.

Constructed treatment wetlands also have some limitations such as, large land area required, long time period required for growth of vegetation and achieve efficient treatment capacity, large open area with standing water can be a breeding ground for mosquitoes and insects, construction of wetlands can be affected by areas with high water table and steep topography, and wetland performance is based on usage and climatic conditions.

Constructed treatment wetlands are designed such that wastewater from a source flows in the wetland and exits after some period of time. Constructed wetlands are lined such that there is no effect on groundwater. The time for which water remain in the wetland is called the hydraulic residence time (HRT). One of the important factors in designing of a wetland is the hydraulic loading rate – which is loading on a water volume per unit area basis. Inflows to a wetland include wastewater inflow, precipitation and storage. Losses from a wetland include effluent discharge, evapotranspiration and transpiration from the plants.

Generally, wastewater treatment constructed wetlands are of two types: Surface flow wetland and sub-surface flow wetland (Internet reference 1). Surface flow constructed wetland (figure 1) are very similar to natural wetlands as they are designed to maintain a 4-18 inches deep water level above the soil. Subsurface flow constructed wetlands (figure 2) have a 1-2 feet media layer of rock or gravel and are designed to maintain the water level just below the media layer.

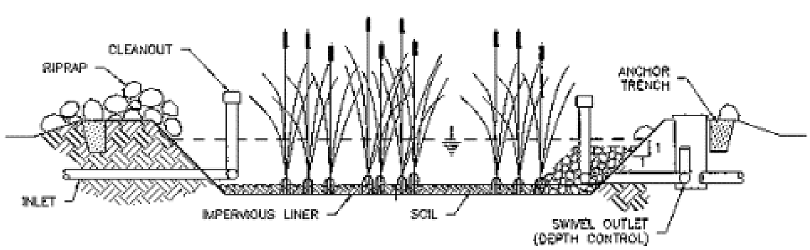

Figure 1. Surface flow constructed treatment wetlands (Constructed wetlands 2002).

The media surface is unexposed to the atmosphere in the sub-surface constructed wetlands whereas the water surface is exposed to the atmosphere in the surface flow wetlands. The biological treatment in the sub-surface flow wetlands is anaerobic as the media is unexposed to the atmosphere but aerobic treatment of wastewater occurs in the surface flow wetlands. The presence of media in the sub-surface flow wetlands makes it more efficient than the other type, because the rocks (used as media) create a lot of pores and crevices for the microorganisms to react with the wastewater.

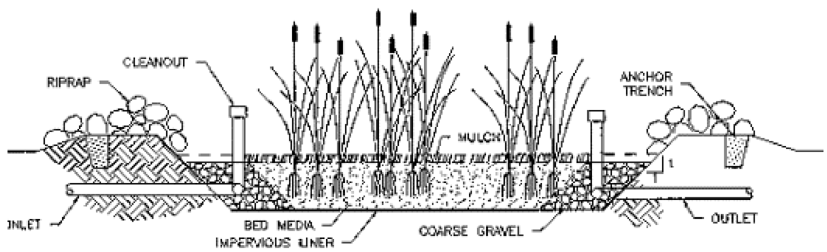

Figure 2. Sub-Surface flow constructed treatment wetlands (Constructed wetlands 2002).

Constructed wastewater treatment wetlands can be used to treat wastewater from different sources like: (Magmedov, V. 2002)

- Sewage (from small communities, individual homes, farms, businesses)
- Municipal wastewater
- Septic tanks
- Storm water
- Agricultural wastewater (including livestock waste, runoff, and drainage water)
- Landfill leachate
- Partially treated industrial wastewater
- Drainage water from mines
- Runoff from highways

Components of a constructed wetland

To understand the wastewater treatment processes and nutrient removal processes in the wetland, it is important to know the main components of the wetland and the factors that influence the wetland performance. The main components of the wetland are wetland vegetation, soil or substrate or media, water column and living organisms in the wetland.

- *Wetland vegetation*: Plants used in wetlands should be able to adapt to water logged conditions and local climatic conditions. Such emergent plants should be resistant to high pollutant levels. Commonly used hydrophytes in the constructed wetland are reed canary grass, softstem bulrush, sedges, wild rice, soft rush, etc. Some of the important functions of vegetation in the wetlands are: to produce oxygen (needed for aerobic reactions) during photosynthesis, reduce velocities of inflowing water and thereby create better conditions for sedimentation of suspended solids, improve hydraulic conductivity of the substrate or media, and uptake nutrients from wastewater, stabilize substrate and enhancing its permeability.
- *Soil or substrate*: Substrates for wetland include soil, sand, gravel, rocks, etc. Constructed wetlands generally use gravel as the substrate as it provides a larger surface area for biological and chemical processes to take place and also provide site for suspended solids and removed pollutants. Course gravel as opposed to soil or fine gravel will provide high hydraulic conductivity in the wetland, which is required to stabilize the hydraulic retention time of the wetland.
- *Water column*: Water in the wetland is required for the occurrence of the biochemical reactions. It also acts a medium of transport for organic solids, nutrients, gases, etc.
- *Living organisms*: Of all the living organisms found in a wetland, microorganisms like bacteria, fungi, protozoa, etc play an important role in the treatment of wastewater. These microorganisms help in biochemical reactions taking place in the wetland as a part of the treatment process.

Wastewater treatment in wetlands

Wastewater treatment in wetlands include removal of pollutants like organic material, suspended solids, pathogens, toxic waste, etc and nutrients like nitrogen and phosphorous. Processes of removal of pollutants and nutrients in wetlands can be broadly classified in to physical, chemical and biological processes. (Sundaravadivel 2001)

- *Physical processes:* Physical processes include filtration and sedimentation. Vegetation in the wetland acts as hindrance for the flowing water, there by reducing velocity and helping in sedimentation of suspended solids. The substrate in the wetland acts as a medium for filtration process.
- *Chemical processes:* some chemical processes that occur in constructed wetlands are precipitation of heavy metals, destruction of pathogens due to photochemical reactions.
- *Biological processes:* The main biological processes occurring in wetlands that results in removal of pollutants and nutrients are: photosynthesis, respiration. Fermentation, nitrification, denitrification and phosphorus removal. Photosynthesis helps in maintaining the oxygen supply for plants. Respiration helps in maintaining dissolved oxygen content in the water. Fermentation leads to decomposition of organic carbon. Nitrification and denitrification are processes of nitrogen cycle that results in removal of nitrogen. Phosphorus removal process results in removal of phosphorous from the wetland.

Removal of BOD (biochemical oxygen demand), which is a measure of rate of oxygen consumption of organic matter by microorganisms), is removed by processes of biological degradation and sedimentation. Biological degradation of organic carbon in the organic matter takes place in the wetland in aerobic conditions to produce CO2 and in anaerobic conditions to produce methane. Suspended solids are removed by sedimentation, filtration. Suspended solids are removed by adsorption on the substrate (gravel). Pathogens trace metals are removed by sedimentation, filtration, adsorption and exposure to sunlight. Trace metals are reduced by processes like plant uptake, soil or substrate adsorption and precipitation of the compounds of the metals.

Removal of nutrients

Nitrogen and phosphorous are two main nutrients found in wastewater in high quantities. Nitrogen is mostly found in the form of nitrates in the water. Some of the problems associated with high levels of nitrates in drinking water or surface water are: serious health effects in humans and eutrophication in lakes and ponds. High levels of Phosphorus in surface water can also cause eutrophication in lakes. Wastewater from agriculture and sewage contains high levels of these nutrients and constructed treatment wetlands are capable of reducing their levels.

Nitrogen removal: The process of nitrogen removal by bacterial conversions in wetlands follows a series of reactions as in a nitrogen cycle (figure 3). The nitrogen cycle has 3 main processes. Ammonification is the conversion of organic N to NH_4^+. Nitrification is a two step process – conversion of NH_4^+ to Nitrite and conversion of nitrite to nitrate. The third process is denitrification – where nitrates convert to nitrites and conversion of nitrites to organic N.

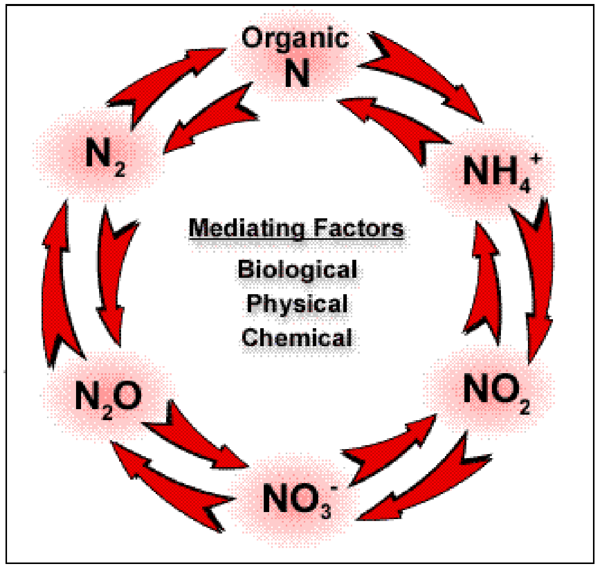

Figure 3. Simplified nitrogen cycle (Nitrogen cycles project)

In wetlands, the nitrogen removal process starts with the nitrification. It is a two step process, where the nitrogen fixing bacteria takes energy from the process of ammonification and carbon source to convert nitrogen to different forms. Ammonia ion is oxidized in the presence of oxygen by nitrosomonas bacteria.

$$NH_4^+ + O_2 \rightarrow NO_2^- + 2H^+ + H_2$$

The nitrite is then oxidized to nitrate in the absence of oxygen by the nitrobacter bacteria.

$$2\ NO_2^- + O_2 \rightarrow 2\ NO_3^-$$

The next step is denitrification, where nitrates are reduced to organic N. Denitrification occurs under anaerobic conditions and in the presence of organic matter – which is the carbon source. This reaction is catalyzed by *Pseudomonas* sp. bacteria. The N formed from denitrification is released in to the atmosphere in the form of nitrous oxide, thereby removing nitrogen from the wetland system.

$$NO_3^- + C\ (\text{organic}) \rightarrow N_2 + CO_2 + H_2O$$

Nitrification is effected by factors like availability of dissolved oxygen, temperature and pH of the wastewater. Denitrification is effected by factors like absence of oxygen, temperature, pH, availability of carbon source, nitrate availability, hydraulic load and HRT. (Bastviken 2006)

Nitrogen is wetlands can also be removed by nutrient uptake of plants. The plants uptake nitrogen in the form of ammonium or nitrate, which is then stored in the plant in the organic form. The uptake capacity of emergent plant species in constructed wetlands can vary from 200 to 2500 $Kg.ha^{-1}year^{-1}$. Factors effecting nutrient uptake of plants is growth rate of plants, concentration of nutrients in the plant tissues and climatic conditions. The major portion of the nitrogen removal is through bacterial conversion as compared to nutrient uptake by plants.

Phosphorus removal: Phosphorus is present in the water in the form of orthophosphate and organic phosphorus. It is found in the wetlands as part of sediments. Phosphorus cycle in wetlands is shown in figure 4.

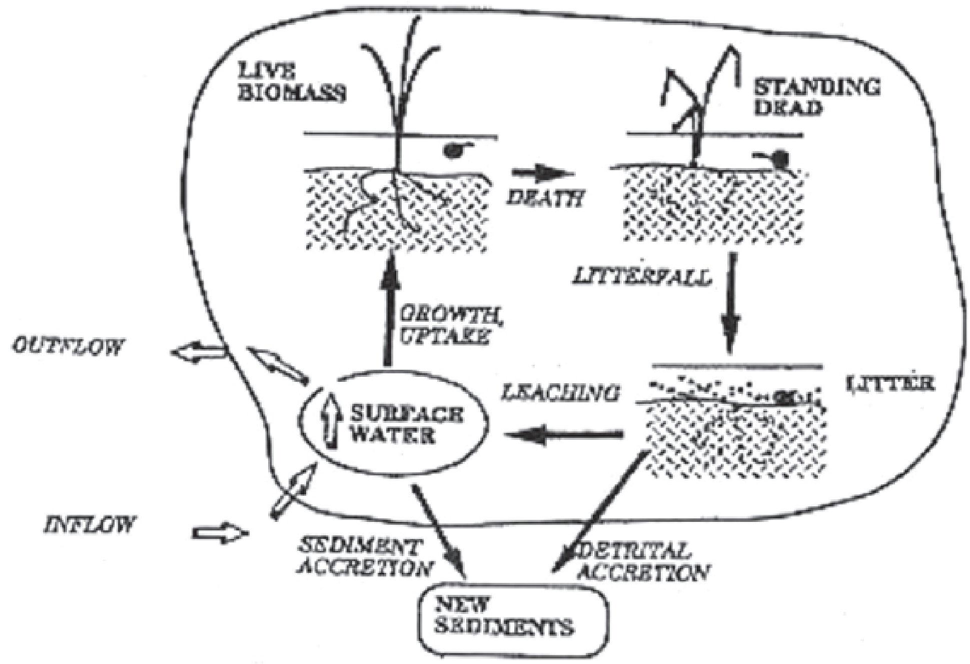

Figure 4. Phosphorus cycle in wetlands (Sundaravadivel 2001)

Adsorption of is the most important phosphorus removal process in the wetlands. Adsorption of phosphorus occurs due to reactions with iron, calcium and magnesium present in sediments. Adsorption of phosphorus to iron ions takes places under aerobic and neutral to acidic conditions to form stable complexes. If the conditions are anaerobic, adsorption to iron ions is less strong. Adsorption to calcium ions takes place under basic to neutral pH conditions. Thus adsorption of phosphorus to the ions removes it from the wastewater. Adsorption is reversible process and each substrate has a particular capacity until it cannot adsorb any more phosphorus. (Verhoeven 1999)

Phosphorus can also get precipitated with iron or aluminum ions. Under this process, phosphate from the water is fixed in the matrix of phosphates and metals. Decomposition of litter (dead plants) and organic matter in the wetland also takes up phosphorus. This process results in storage of phosphorus in the organic matter which will be released eventually. Growing plants take up nutrients like phosphorus, there by reducing levels in the wetland. The plant uptake of phosphates varies from 30 to 150 Kg $ha^{-1}year^{-1}$. (Sundaravadivel 2001)

As compared to nitrogen, removal of phosphorus does not result in its complete removal from the wetland system. Nitrogen is eliminated form the system, in the form for N_2 gas, but phosphorus is only removed from the water and is either adsorbed to the metals ions, or taken up by plants or fixed in the clay minerals.

Wetland performance

The performance of a constructed treatment wetland is defined as the efficiency of the wetland in removing pollutants and nutrient from the wastewater. The performance of wetland depend upon the following factors: inflow rate, outflow rate, pollutant loading rate, hydraulic retention time (HRT), hydraulic loading rate, climatic conditions, temperature, pH, oxygen availability, wetland design components – substrate, vegetation and living organisms. (DeBusk 1999). The wetland design factors, that include influent and effluent concentrations, inflow and outflow rates, HRT, loading rate, etc, should be selected accurately to meet the objectives of the constructed wetland. The wetland performance tends to decrease if the influent concentration becomes close to the background concentration of the wetland, while the effluent concentration is in its desired range. But the wetland performance will increase if the loading rate increases while the outflow concentration may or may not change. .

Presence of oxygen concentration of the sediments in the wetland, increase the rate of processes in the nitrogen cycle. In phosphorus removal, oxygen content of the sediment increases the binding capacity of phosphorus to metal ions.
The two important factors effecting nutrient reduction in the wetland are temperature and the type of vegetation used in wetlands. According to the study by Sakadevan 1999, Constructed wetlands are capable of removing N and P and thereby treating wastewater. The wetland performance also depends on the design of wetland. Low hydraulic loading and higher retention times increase the P and N removal. Some case studies presented show efficiency of wetlands to remove nutrients from wastewater and the relationship between various factors affecting the nutrient removal performance. These case studies were chosen to discuss various studies being done in the field of wetland performance and the factors affecting it.

Case studies
Case study 1: Picard et al. 2005 studied the interacting the effects of temperature and plant type on the nutrient removal in the wetlands. The processes taking place in the wetlands are influenced by solar radiations and surrounding temperatures. The biological process taking place in the wetlands are almost get ceased when the temperatures drop below 10^{o}C. The nitrogen removal process in the wetlands is more affected by temperatures as compared to phosphorus removal because phosphorus removal mostly depends on sediment adsorption rather than biological processes. This study was done to answer questions like:

- Change in nutrient removal efficiency with change in seasons with respect to different plant communities
- Do plant species have specific removal rate for nutrient removal?
- Effect of insulating microcosm on the nutrient removal in extreme temperatures.

The experiment was conducted in Ohio, where the study in sex replications. The experiment consisted of 72 microcosms and each microcosm contained six vegetation treatments. The four species used were *Carex lacustris, Scirpus validus, Phalaris arundinacea, and Typha latifolia*. Half of the treatment was subjected to insulation. The experiment was run for one year. Nutrient additions were done three times a week.

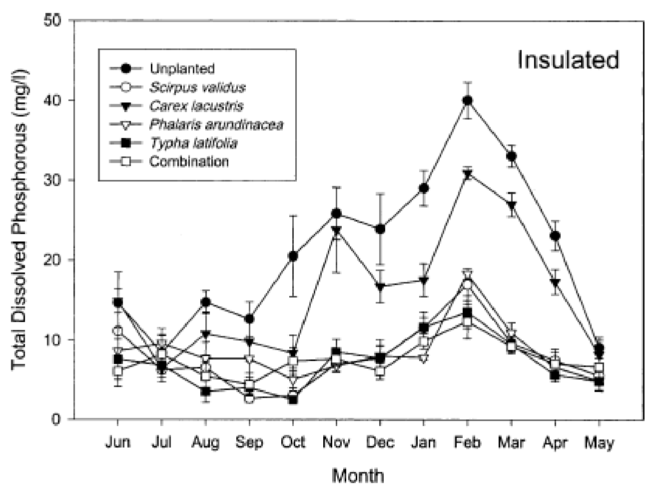

Figure 5. Mean total dissolved nitrogen values for plant treatment with insulated treatments. **(**Picard et al. 2005)

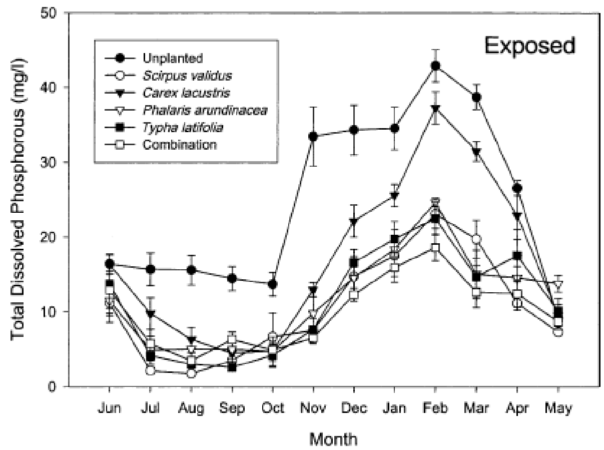

Figure 6. Mean monthly total dissolves phosphorus for each plant treatment within insulation treatments. (Picard et al. 2005)

During the study, the total dissolved nitrogen (TDN) output of insulated microcosm was significantly less than of exposed microcosm for *Phalaris arundinacea and Typha latifolia* and plant combinations. Total dissolved phosphorus output of insulated microcosm was less than that of exposed microcosm for *Scirpus validus, Phalaris arundinacea, and Typha latifolia* (figure 5 and 6).

Insulated microcosms were more effective in removing nutrients than exposed microcosms. These microcosms have large nutrient removal rates during on year of the study. They also represented a specific pattern in season nutrient removal. Nutrient removal was higher in growing season and lowest in the cold season showing the temperature dependence on wetland performance. Variation in seasonal phosphorus removal was less as compared to nitrogen, because of year around phosphorus removal. This shows that biological process involved in the nitrogen removal are temperature dependent. Planted microcosm outperformed unplanted microcosm in nutrient removal. The higher nutrient uptake is due to the reason that plant process ear more stable in planted systems. No definite pattern of species-specific nutrient removal was observed. But the specificity of the plant species is due to nutrient needs, plant physiology and plant physiology.

Conclusions*:* 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.

Case study 2: Fisher and Acreman 2004 did a literature review study on nutrient removal of wetlands. They reviewed more than 57 wetlands from 60 publications or papers from 16 countries. The three questions they tried to answer were:

- Is P or N retained in natural wetlands?
- Which type of wetland is most effective at removing N and P?
- What are the main influences on changes to nutrient loading?

The third question is relevant to this paper. The main factors effecting nutrient loading are vegetation process, sediment oxidation, hydraulic loading and retention time, nutrient loading, carbon content of wetland, flow pathways.

The results based on the literature review, prove that reduction in N and P loadings depend upon the following three factors: the degree of water logging, the rate of nutrient loading and duration of nutrient loading (figure 7). Removal of N and P requires a different type of wetland for each. The removal of P increases if the substrate is non- reducing, which is in contrast to the condition required for efficient N removal. Hydraulic loading and retention times are significant in determining sedimentation rates, the contact time between nutrient load and wetland sediment and vegetation. The studies also showed that P removal is positively related to P loading and N removal is negatively related to N removal.

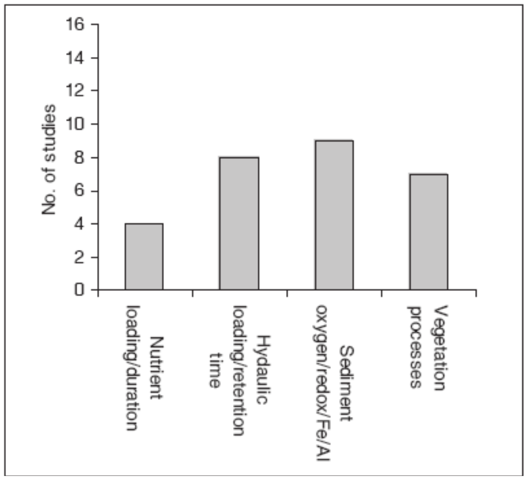

Figure 7. Most common Factors effecting nutrient reduction abilities in wetlands studied by Fisher and Acreman 2004

Case study 3. Fink and Mitsch 2004 studied the removal of nitrogen and phosphorus from a riparian wetland that receives flow from an agricultural watershed. The main objective of the experiment was to find out that whether this particular wetland design will be a net source or sink of nitrates and phosphates, how effective is the wetland deign in reducing nutrient levels from storm events in that watershed and finally how effective the wetland would be for nutrient removal with complex surface hydrology of the watershed.
The experiment was done at Indian Lake Demonstration Wetland in Logan County, Ohio. A 17 ha watershed out of which 14.2 ha is under agriculture, drains into the wetland. The wetland has four separate sequential basins that are connected to each other by sub surface flow which results from groundwater recharge from each basin to the next basin. The hydraulics for discharge in to each basin and the hydrologic response coefficient (amount of runoff from an individual storm event) were calculated. Precipitation was measured during the duration of the experiment. Samples were taken twice per month from October 1998 and through September 2000. The surface inflow over two years was 646 cm/year (over the entire wetland area of 1.2 ha), with groundwater inflows contributing 422 cm/year.

Results: 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.

Comparing the effect of storm events on nutrient reductions, the authors found out that nutrient concentrations before and after the storm events were similar to those from regular sampling. The mean loading rate of NO_3^- did not increase significantly during most storms, while the mean loading and retention rate for TP did increase significantly.

Conclusions: 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.

Case study 4. Andersson et al. 2005 studied the nitrogen and phosphorous removal performance for four free water surface (FWS) wetlands. These wetlands had inflow coming from a wastewater treatment plant (WWTP) with varying degrees of pretreatment. This study was done in south Sweden. Two wetlands received wastewater from WWTP that was both biologically and chemically treated, where as the other two wetlands received influent that was only chemically treated and undergone settling process. Data on the operation times of the wetlands and the emergent macrophytes planted each wetland was recorded. Flow was measured at inlet and outlet of each wetland and samples were collected weekly or biweekly.

Results: All the fours wetlands had good removal efficiencies varying from 1-41 Kg per ha per year with the outflow concentration of the wetlands below the required level of 0.5 mg/L. The relative efficiencies between the wetlands were different because of the difference in the inflow rates and concentrations.
The outflow concentrations from the four wetlands were 15ppm, which is below the Sweden standards. The area specific removal rate was highest in the wetlands that received highest loads of nitrogen and nitrates – which help in increasing the denitrification rate. Difference in the N removal rates between the wetlands was due to the different inflow concentrations and hydraulic loads.

Comparing the two plants that received biologically and chemically treated wastewater, the second one had a greater nitrate removal rate than the other. The possible reasons for that are higher hydraulic efficiency of the second wetland, it was a deeper wetland which resulted in the formation of more anaerobic zones, and the second wetland was not regularly harvested which means that more organic matter was available (for degradation reactions) compared to the other wetland.

Conclusions: Figure 8 shows a definite reduction in the nitrate concentrations in the effluent from the two wetlands that received chemically treated wastewater. Hence it can be concluded that all the four wetlands showed efficient removal of nitrogen and phosphorous over the three year period.

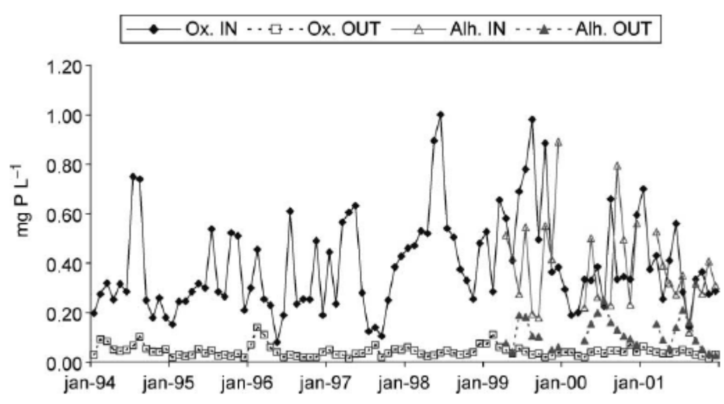

Figure 8. Influent and effluent nitrate concentrations in the two wetlands that received chemically treated wastewater. Ox – first wetland, Alh – second wetland.

The removal capacities for all the fours wetlands were not comparable. The removal efficiencies depended on inflow, influent loading, and type of pretreatment. It also depended on the HRT of the wetlands, loading rates, oxygen concentration and organic matter content Thus, it can be concluded that wetlands can effectively treat wastewater from municipal WWTP, and the wetland have to be designed considering all the above factors.

Case study 5. Maine et al. 2005 studied the treatment of wastewater from a metallurgic industry for removal of nutrients and heavy metals. The compared the performances of large scale wetland to prototype wetland. This experiment was done in toll manufacturing industry in Argentina.
The two wetlands have different designs and different flow paths for the influent. The large scale wetland has a baffle in the centre of the wetland, while the prototype wetland had horizontal flow. They were planted with different macrophytes. Twenty four water sampling were done at the inlet and the outlet of the wetlands for two year period. Various parameters were measured over the two year period at the inlet, outlet and outlet bottom of the wetlands like temperature, conductivity, dissolved oxygen , pH, nitrite, nitrates, inorganic N, iron, chromium, nickel, zinc, phosphorus, COD and BOD.

Results: The results from statistical analysis of the data showed that concentration at the outlet were significantly lower than the inlet for all the parameters except, SRP and ammonia (figure9). Oxygen concentration were different at surface and the bottom for most parameters, which can used to conclude that nutrients levels in the effluent can be improved if outlet was at the surface rather than the boron of the wetland.
Nitrate, nitrite and sulfate concentrations at the outlet were reduced by 70%, 60% and 44%, whole ammonium concentration doubled. Mineralization of organic matter is a good source for ammonium, which was not nitrified, because of low oxygen concentrations. Inorganic N was reduced by 53% of the incoming concentrations.

Calcium and alkalinity concentrations were reduced by 65 and 37% respectively. Removal percentages were greater when the pH was higher at the outlet, which suggests it depends on pH. SRP concentrations at the inlet were lower when water pH was higher. During the experiment period, Fe, Cr, and Ni had removal efficiencies of 95, 86 and 67 % respectively. The high sulfate concentration
in the incoming wastewater suggest that most of the organic matter mineralization took place at the expense of biological sulfate reduction.
Total phosphorus show temporal and spatial variations. After first year of the experiment, TP showed a significant increase at the inlet while TP concentration at the outlet was not significantly different.

Conclusions: Both the small-scale and the large-scale wetlands efficiently removed metals from the effluent of a metallurgic plant. The small-scale and the large scale wetlands reduced Cr, Ni, Fe concentrations by 81%, 66%, 82%, and 86%, 67%, 95%, respectively. Figure 6 shows the wetland performance of the large scale wetland in removing SRP from the metallurgy plant over the 2 year time period. But the small-scale wetland was more efficient in removing SRP than the large-scale.

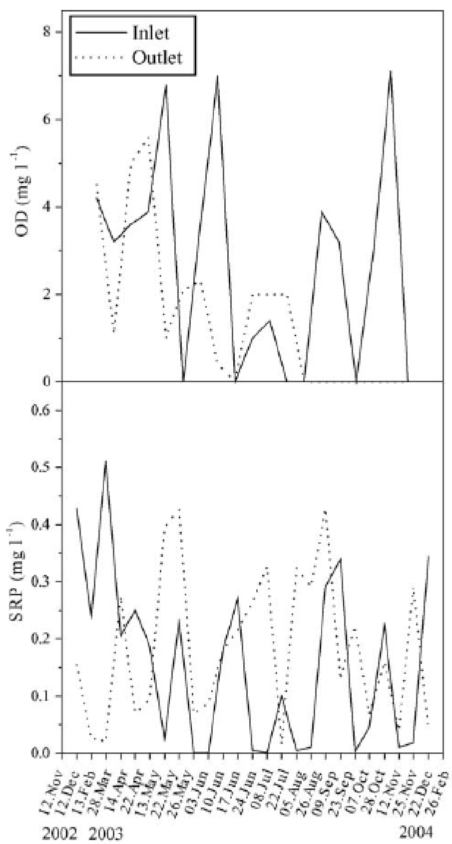

Figure 9. Inlet and outlet concentrations of dissolved oxygen and SRP of the large scale wetland

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