Removal Mechanisms in Constructed Wastewater Wetlands

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ABSTRACT

The use of constructed wetlands is a relatively new technology but the system is gaining popularity due to its low tech system for treating wastewater (DeBusk, 1999b).Constructed wetlands have found to be effective in treating domestic wastewater where municipalities are concerned with reducing suspended solids, organic matter, phosphorus, nitrogen, and pathogens. Constructed wetlands mimic natural wetland systems but can have greater control with what purposes the wetland serves (Lorion, 2001). The purpose of constructed wetlands is to remove contaminants. These contaminants if exposed to receiving streams pose health hazards to the general public, aquatic organisms, and the environment. Suspended solid removal is important in wastewater treatment for the survival of the receiving stream for which discharging. If vast amounts of solids are present sunlight will not be able to reach plants and oxygen levels in the water will decrease and cause harm to the receiving stream (Murphy, 2007). The removal of organic matter is also very important due to decreased oxygen levels that can result in receiving streams. Recent movements and stricter regulations have been in the removal of nitrogen and phosphorus which contribute to eutrofication in receiving waters. The presence of pathogens and metals are major health concerns which make removal very important. The understanding of the mechanisms that drive removal of these contaminants is crucial with what type of constructed wetland being selected and whether suitable for a specific location.

KEYWORDS

Removal Mechanisms, Constructed Wastewater Wetlands, Free Water Surface, Vegetated Submerged Beds

INTRODUCTION

There are two major types of constructed wastewater wetlands. The first is called a free water surface wetland (FWS). A FWS wetland encompasses shallow water flowing over plant media and water depths that vary through the wetland. Typically these wetlands resemble natural wetlands and include mineral or organic soil underneath vegetation. Vegetation includes reeds and cattails but can also include floating plants which are also known as macrophytes. The second type of constructed wetland is a vegetated submerged bed wetland (VSB). A VSB contains coarse substrate media such as gravel which the water travels through. The top of the water level is below the surface of the media and plant roots are allowed to grow in the coarse media. These wetlands remove contaminants by different means but the basic processes and mechanisms are the same for both. Figure 1 below shows the various types of constructed wetlands.

Wastewater wetlands encompass many processes and mechanisms in the removal of contaminants. The basic three are physical, biological, and chemical removal processes. Physical processes are often used in primary treatment of traditional wastewater treatment systems. The processes are no different than in wetlands. Water that flows through wetlands moves rather slowly due to resistance from plant matter and a uniform sheet flow of water. The plants in the wetland help trap sediment but not as much as sediment that settles from lower velocity. This low flow allows particles to settle out and this is also helped by laminar flows in most wetlands (DeBusk, 1999a). By using gravity and the differences in relative densities of suspended material, particles are allowed to settle in the wetland (Interstate, 2003).

One of the most important mechanisms for pollutant removal in wetlands is done by biological means. The main and most well known way this is done is by plant uptake (DeBusk, 1999a). When plants directly uptake contaminants into their root structure, this process is called phytodegredation. When plants secrete substances that add to biological degradation, this process is called rhizodegradation. The process from where contaminants entered the plants biomass and transpired through the plant leaves is called phytovolatilization (Interstate, 2003). Microorganisms in wetland soils uptake and store nutrients but the metabolic functions are more crucial in organic pollutant removal. The bacteria, mostly in the form of soil bacteria, use the carbon found in organic matter as an energy source and convert to carbon dioxide in aerobic conditions and methane in anaerobic conditions. The microbial metabolism is also very important in the removal of inorganic nitrogen (DeBusk, 1999a).

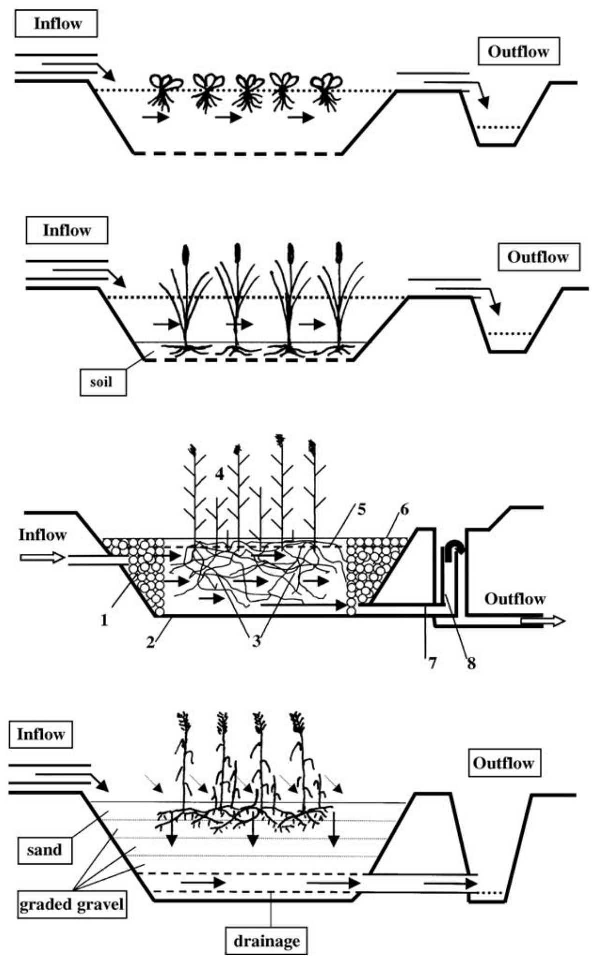

Figure 1 – The various types of constructed wetlands (Vymazal, 2006).

The last process involved in contaminant removal in wastewater wetlands is by chemical means. This process includes sorption, photo oxidation, and volatilization. Sorption is the most important chemical process and involves the moving of charges from aqueous phases to solid phases. Sorption includes the processes adsorption and precipitation. Adsorption refers to the transferring of ions to soil particles and precipitation involves converting metals to insoluble forms. Photo oxidation utilizes the power of sunlight to breakdown and oxidize compounds. Volatilization breaks down the compound and expels it into the air as a gaseous state. These physical, chemical, and biological processes make up the foundation from which wastewater wetlands remove pollutants (DeBusk, 1999a). Figure 2 below shows an overview of the mechanisms that are present in a FWS wetland.

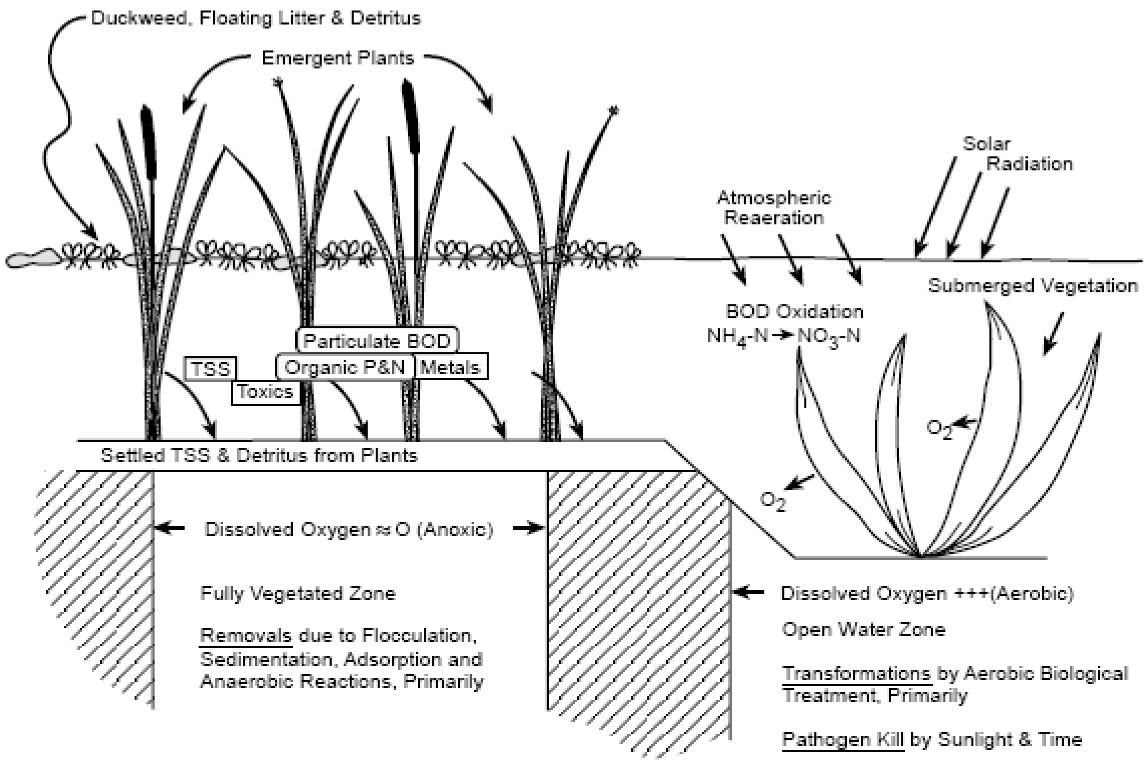

Figure 2 – Mechanisms present in a FWS wetland (EPA, 1999).

MECHANISMS OF SUSPENDED SOLIDS REMOVAL

The two types of wastewater wetlands offer different approaches at which suspended solids are removed from the system. It is important to know the removal mechanisms for both systems starting with the free water surface wetland. The FWS wetland removes suspended solids primarily by flocculation/sedimentation and filtration/interception. Settling by gravity can be divided into discrete settling and flocculent settling. Both of these processes are influenced by particle size, shape, specific gravity, and properties of the fluid medium. Discrete settling is when a particle settles independently on its own with no contact from other particles. The settling velocities of these particles can be reasonably determined from Newton's Law and Stokes' Law. Flocculent settling cannot be as easily determined as discrete settling and must be found experimentally. Flocculent settling involves the interacting of particles changing size and characteristics. The formation of larger flocculants results from charge imbalances on the surface of the particles. If larger flocs are formed then the settling of the new particle will occur faster. FWS wetlands can typically see hydraulic loads about .01 m/day to .5 m/day. If assuming a hydraulic load of .3 m/day which a typical system velocity of 50 m/day with a depth of .8m then larger particles will settle out in about 2.7 days or in the first 133m of the wetland. Smaller particles would take about 200 days and would need 11,000m of wetland to settle out. The larger particles would be removed in the primary part of the wetland whereas the smaller particles may be flocculated by varying velocity gradients imposed by plant stems. Filtration does not typically play a large part in suspended solisa removal of FWS wetlands since the plant stems of plants are too far apart. Interception and adhesion to plant surfaces play an important part in solid removal. The surfaces of plants in wetlands are coated with active layer of biofilm called periphyton which can absorb colloidal and soluble matter. These solids may then be metabolized and then converted to gases or biomass. The material then may renter the water column. There has been little research on this mechanism of removal in FWS wetlands. Typical total suspended solids concentration is around 3 mg/L. The mechanisms for FWS wetlands varies in regards to the mechanisms involved with VSB wetlands (EPA, 1999).

When dealing with removal of suspended solids in VSB wetlands, the main criteria that should be addressed are the hydraulic design and microbial characteristics of the substrate (Manios et al., 2003). Due to low velocity and large surface area of the media in VSB wetlands, they have proven effective in removing suspended solids. VSB wetlands offer gravity settling, straining, and adsorption onto gravel and plant media (EPA, 1999). It has been found that 60- 75% percent of solids removal in VSB wetland occur in the first one third of the wetland. One of the major concerns with VSB wetlands is the clogging of the filter media. As suspended solids pass through the soil media, it can clog pores and reduce the hydraulic conductivity of the media producing head losses at the entrance of the wetland (Manios et al., 2003). It was thought that plant roots might help prevent clogging but no research has proven this (EPA, 1999). In order to stop clogging larger particle media (10-15cm) that offer larger void space and less shear resistance to flow were chosen. This approach however altered the plants root network and thus root systems were not able to grow in the larger void space. The larger void space also decreased the surface area for which bacteria to grow on. This was important comparing to the large surface area of smaller media. It was then chosen that smaller rock media of less than 5cm to solve the above problems. Research of five different gravel based VSB wetlands being used for tertiary treatment in the United Kingdom have been analyzed over a two year period. Over the two years the wetlands removed an average 82% of the total suspended solids with an average effluent value less than 5 mg/L (Manios et al., 2003). VSB wastewater wetlands offer a great reduction in the amount of suspended solids but there are concerns with the clogging of the media. By using different types of media, clogging can be minimized and proper suspended solid removal can be achieved.

MECHANISMS OF ORGANIC MATTER REMOVAL

Organic removal is different for FWS and VSB wetlands but both share some of the same principles. First these principles will be addressed and the specifics of each system looked at more closely. Organic material is made up of about 50% carbon which microorganisms use an energy source. The vast arrays of microorganisms are adapted to aerobic surface waters or anaerobic soils. The aerobic microorganisms consume oxygen to breakdown organics which provides energy and biomass for the microorganism. Anaerobic bacteria breakdown organic matter to produce methane. Biological oxygen demand is used to measure how much oxygen microorganisms are consuming to break down organics. It is important that there is enough oxygen in the water after the wetland so that plants and animals can survive. Wastewater wetlands are also capable of storing organic carbon in plant biomass thus making wastewater wetlands natural consumers of organic carbon (DeBusk, 1999b).

FWS wetlands can remove organic matter by physical means and biological means. Physical removal is similar to suspended solid removal in that the mechanisms are similar and it is not uncommon for effluent to have similar characteristics. The separation processes of organics include sorption and volatilization. The biofilms located on plant surfaces offer pathways for plants to break down organics. Although the amount volatile organic compounds entering wastewater wetlands is fairly low, the removal rate of VOCs are in the 80-96% range. The biological breakdown of organic matter is a very important one. Organisms will break down organic matter in order to produce new biomass, reproduce, and sustain life. Energy is a key element in any biological system and it can be in many forms. The main types of reactions with organic matter include aerobic, anoxic, and anaerobic. In an aerobic environment, oxygen is present and serves as the terminal electron acceptor. This is the most efficient conversion of starting material to end products. In an anoxic environment nitrates, sulfates, and carbonates serve as the terminal electron acceptor which are reduced to form oxides. Anoxic reactions are less efficient than aerobic reactions. Anaerobic environments use the organics as the terminal electron acceptor and donor. The reactions the organisms use to break organics into energy are reactions that yield energy for the organism. These include oxidation and reduction reactions, hydrolysis, and photolysis. These reactions produce methane and is the least efficient of the three reactions. When looking at biological breakdown of organics, it is important to look the different types of organism classes present. Benthos organisms are present on the bottom of the plant matter and in sediments. Periphyton are organisms that are attached to leaves and stems of rooted plants. Plankton are organisms that are dictated by currents. Neuston are organisms resting on the surface of the water. Nektons are organisms that have the capability to navigate the water on their own will. Bacteria, actinomycetes, and fungi play maybe the most important role in breaking down organic matter. Macrophytes are aquatic plants located on top of the surface of the water which play an important role in producing oxygen to the water (EPA, 1999). Figure 3 below outlines the major organic matter transformations in a FWS wetland.

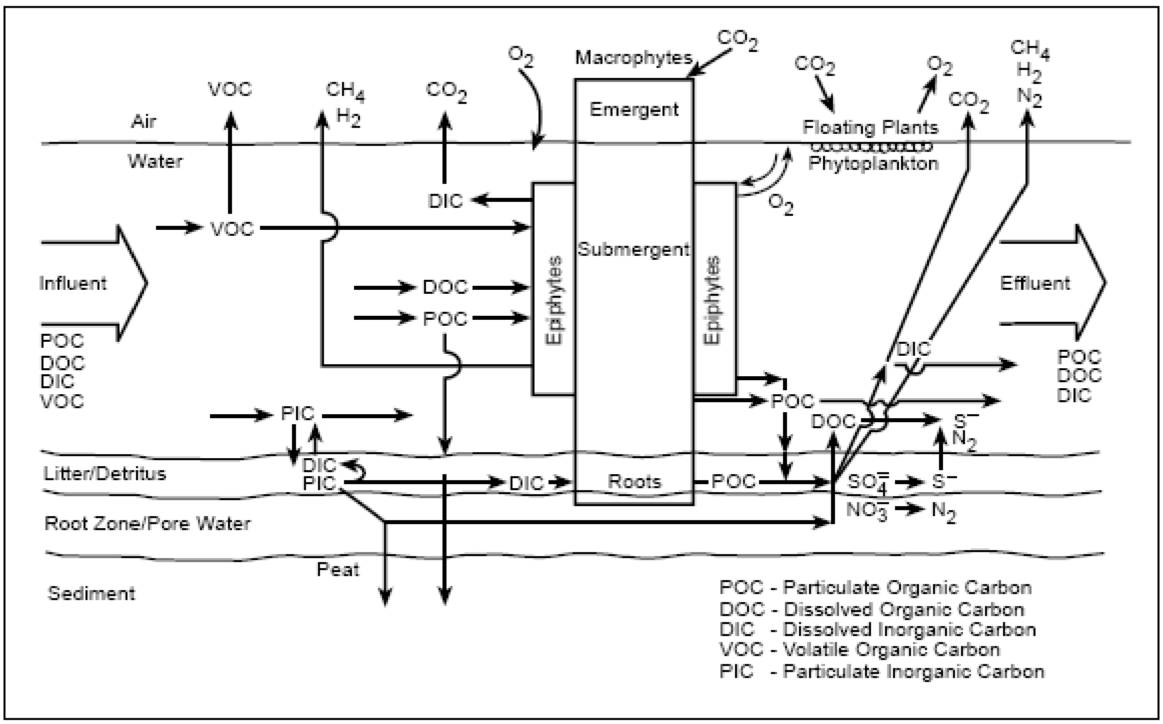

Figure 3 – Organic matter transformations in a FWS wetland (EPA, 1999).

The mechanism for organic removal in VSB wetlands is a little different than in FWS wetlands since VSB wetlands function as fixed film bioreactors. The particulate organic material entering a VSB wetland undergoes a similar mechanism as suspended solids. The particles undergo hydrolysis and produce soluble organic matter which enter the media and attach to biofilm media and then further decomposed. The amount of decomposition of organic matter is rather low since average dissolved oxygen concentrations in a VSB wetland are less than .1 mg/L. The predominant biological mechanism for organic removal is done by aerobic/facultative means. VSB wetlands have strong reducing capabilities which make the predominant metabolic mechanism an aerobic manner. Anaerobic functions include methanogenisis, sulfate reduction, and gentrification which all produce gaseous products. These functions vary with temperature and it is possible that as temperatures increase greater amounts of gas can be released (EPA, 1999). The removal of organic matter drive dissolved oxygen concentrations but much attention has been aimed at nutrient removal due to eutrofication.

MECHANISM OF NITROGEN REMOVAL

One of the important issues when treating wastewater is the removal of nitrogen. There have been many environmental and health problems associated with high amounts of nitrogen in water. High concentration of nitrates in drinking water can cause “blue baby” syndrome in infants. Ammonia that is not ionized can be toxic to marine organisms and aquatic life. High amounts of nitrogen also contribute to eutrofication in which nutrients promote excessive plant growth where plants deplete oxygen in the water. The need for proper nitrogen removal is very important. Nitrogen exists in many forms such as inorganic and organic forms. Inorganic nitrogen includes nitrates, nitrites, and ammonium. In natural environments where oxygen is in surplus nitrogen usually exists as nitrates and nitrites. In environments that lack oxygen, nitrogen is available as ammonium which is the case in wetland soils. As nitrogen containing material settle in wetlands, the matter is either taken up by plants or broken down by microorganisms. Plants use nitrates and ammonium as nutrients which can be stored as organic nitrogen. When plants die the organic nitrogen present accumulates as peat as a long term storage mechanism. Microorganisms break down inorganic nitrogen mostly by denitrification which converts nitrate to nitrogen gas. If nitrogen is in the form of ammonium then this must be converted to nitrate by nitrification. Nitrate removal in wetlands is usually very high (DeBusk, 1999b).

The removal of nitrogen involves a number of processes all which act on different types of wastewater wetlands. These processes include ammonia volatilization, ammonification, nitrification, nitrate-ammonification, denitrification, fixation, plant and microbial uptake, ammonia adsorption, organic nitrogen burial, and ANAMMOX. These are the major nitrogen mechanisms some of which occur in different types of wastewater wetlands. The following will go into more detail on these mechanisms and in which types of wetlands the mechanisms are present (Vymazal, 2006).

As noted before the most important forms of organic nitrogen found in wetlands are ammonium, nitrate, and nitrite. These various forms of nitrogen are required for biological life to function in the wetland. The processes that transform various forms of nitrogen are all necessary for wetlands to function successfully. Ammonia volatilization is the physicochemical process where ammonium is in equilibrium with gas and hydroxyl forms. Usually if the pH is lower than 8.0 and ammonia volatilization does not occur. If the pH reaches as high as 9.3 then ammonia and ammonium ions present exist in a one to one ratio. This means that the losses from volatilization can be significant and has been reported as high as 2.2 g N m-2 d-1. A larger pH can be observed when plants undergo photosynthesis during the day. Ammonification is the process where organic nitrogen is converted to ammonia. The process is biochemical which involves the release of energy which some microorganisms utilize for growth and new biomass. Up to 100% of organic nitrogen is converted to ammonia through a complex process involving the catabolism of amino acids. The process converts amino acids into ammonia by means of aerobically, anaerobically, and obligate anaerobically. The majority of ammonification is done by anaerobic and obligate anaerobic mineralization. The rates of ammonification depend on temperature, pH, C/N ratio, available nutrients, and soil conditions. The optimal ranges include 40-60 degrees Celsius and pH between 6.5 and 8.5 (Vymazal, 2006). This step is crucial before ammonium is then absorbed by plants, solubilized and returned to the water column, converted to gaseous ammonia, or aerobically nitrified by aerobic organisms (EPA, 1999).

Once organic nitrogen is in the form of ammonium, nitrification can take place where ammonium is biologically oxidized to nitrite and then finally to nitrate. Heterotrophic and autotrophic organisms utilize this process in the same manner. Usually nitrification has thought to be a chemoautotrophic process but recent research has shown that nitrification by heterotrophic means is also significant. Nitrifying bacteria utilize carbon dioxide as a carbon source and oxidize ammonia or nitrite to derive energy. Nitrification is carried out by two types of nitrifying organisms. The first step converts ammonium to nitrite and the second converts nitrite to nitrate. The first step is done firmly aerobically; the organisms depend on oxidizing the ammonia for cell growth and energy. Soil organisms include Nitrosospira, Nitrosovibrio, Nitrosolobus, Nitrosococcus, and Nitrosomonas. The carbon source is mostly found from carbon dioxide but carbonate can be used as well. The second step converts nitrite to nitrate and is accomplished by facultative chemolitrotrophic bacteria which can utilize organics for cell growth an energy. The only organism found in soil of freshwater which oxidizes nitrites is Nitrobacter. Nitrification also is influenced by temperature, pH, alkalinity present, and dissolved oxygen. The ideal temperature is from 30 to 40 degrees Celsius. The pH values range from 6.6 to 8.8 and proper amounts of alkalinity and dissolved oxygen must be present. Nitrification consumes 4.3 mg of oxygen and 8.64 mg of alkalinity per mg of ammonia oxidized (Vymazal, 2006). Figure 4 below outlines the major nitrogen transformations in a FWS wetland.

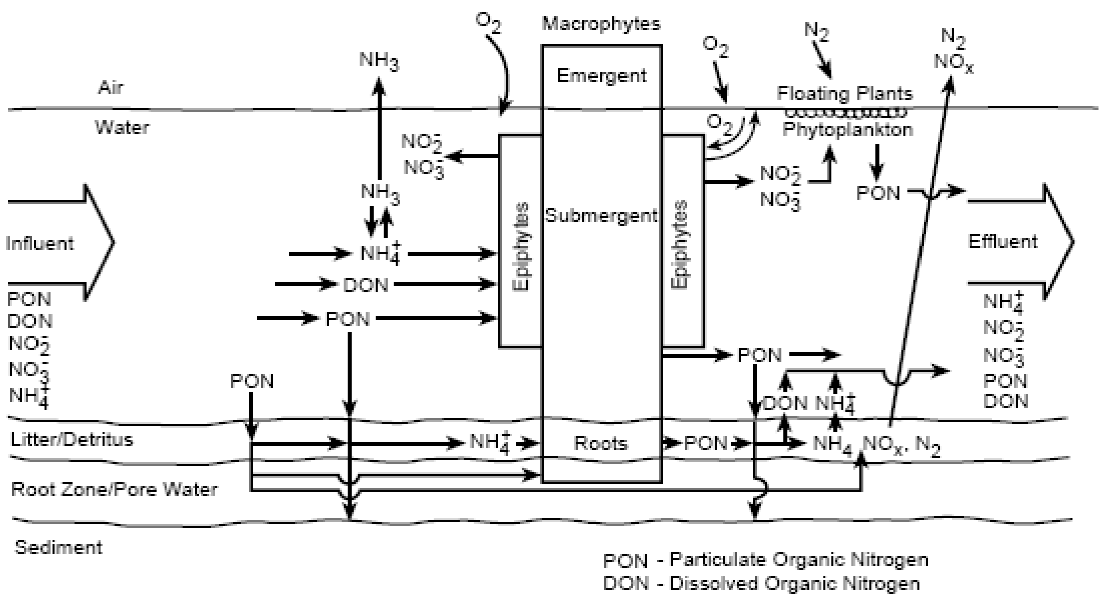

Figure 4 – Nitrogen transformations in a FWS wetland (EPA, 1999).

Nitrate-Ammonification is the first anoxic process after oxygen is depleted in the system. This includes the reduction of nitrate to molecular nitrogen or ammonia. This is performed by two different nitrate reducing bacteria. Denitrifying bacteria produce dinitrogen oxide and nitrogen as major products. The second group produces ammonium as the major product from reduction of nitrate. This process is similar to denitrification where nitrate is converted to nitrogen gas by several intermediates of nitrite, nitric oxide, and nitrous oxide. This reaction is carried out electron accepting nitrogen oxides which receive electrons from available organic substrate all of which is done under anaerobic and anoxic conditions. The reaction is not reversible and is carried out mostly by chemoheterotrophs although many types of organisms are capable of denitrification. The organisms receive energy through the chemical reactions and using organic compounds as a carbon source. Bacillus, Micrococus, and Pseudomonas are important denitrifying organisms in soils and Pseudomonas, Aeromonas, and Virbio are important in aquatic environments. In the presence of oxygen the organisms break down organics into carbon dioxide and water. The electron transport system enables the organisms to denitrify in anaerobic conditions. Denitrification is a process that is similar to the aerobic process but takes place under anoxic conditions (Vymazal, 2006). Denitrification consumes 2.86 g of oxygen per gram of nitrate reduced as organic carbon is consumed. Alkalinity is replenished back into the system as about 3 grams of alkalinity is produced per gram of nitrate reduced (EPA, 1999). There are several factors which influence whether nitrification will take place. These include but are not limited to presence of oxygen, temperature, pH, and presence of denitrifiers. Under low oxygen levels the production of nitrite from ammonia is favored over nitrate formation from ammonia. This nitrite can still be denitrified to nitrogen gas without being converted to nitrate (Vymazal, 2006). A process that goes in the reverse way is called fixation.

Fixation is the process of converting nitrogen gas to organic nitrogen. The reaction can be done aerobically or anaerobically by certain types of bacteria and blue-green algae (EPA, 1999). There are a variety of wetland plants that can fix nitrogen but the process requires a large amount of cellular energy which is not necessary in a nitrogen rich environment (Vymazal, 2006). The process occurs on open water, in sediment, and on the leafs of plants. In natural wetlands fixation plays a more important role but not as important in constructed wastewater wetlands. This is because of the nitrogen rich environment that was created. An important part of nitrogen transfer in wetlands is plant uptake and assimilation. This refers to biological processes that convert inorganic nitrogen to organic nitrogen. The organic nitrogen is then used for energy and cell growth. The forms of nitrogen that are assimilated are ammonia and nitrate. Ammonia is preferred but if waters are rich with nitrate then it may be used as the predominant nutrient. Plants uptake inorganic nitrogen on the surface of the water or under the water's surface. The uptake is greater in the beginning of the growing season and nitrogen is released later as the season progresses. Another similar process is ammonia adsorption where ionized ammonia is adsorbed from solution. The ionized ammonia can be taken up by inorganic sediments and released when the water conditions are right. As the amount of ammonia increases in the water, the amount of ionized ammonia will also increase. Another process involving nitrogen is the burial of organic nitrogen where it is incorporated into the soil of a wetland. This nitrogen that is buried in soil then undergoes processes that ends up in peat. The last process that pertains to nitrogen in wetlands is ANAMMOX which stands for anaerobic ammonia oxidation. This involves nitrite used as the terminal electron acceptor being oxidized to ammonium and then nitrogen gas. Much research still needs to be done on this process and its use in wetlands (Vymazal, 2006).

The previous paragraphs provides an understanding for processes involved with nitrogen in wastewater wetlands but it is necessary to know which processes actually remove nitrogen from the system and for which type of system. Ammonia volatilization, denitrification, plant uptake, ammonia adsorption, organic nitrogen burial, and ANAMMOX are all processes that reduce the amount of nitrogen in the system. FWS wetlands have different ways of removing nitrogen than VSB wetlands since the media in which the water flows is different. Volatilization can be a large reducer of nitrogen in FWS wetlands if the pH of the systems increases. Ammonification does not decrease nitrogen but it gets organic nitrogen in the state of ammonia so that it can be removed by other processes. Ammonification is present in all types of wastewater wetlands. Nitrification also does not remove nitrogen but coupled with denitrification, the two are the major pathway for nitrogen removal. This process occurs in all types of wetlands but has been found to be the limiting step in nitrogen removal. This is because the vast amounts of nitrogen entering the wetlands are in the form of ammonia. Denitrification the primary mechanism of removing nitrogen in wastewater wetlands. Usually the nitrate concentration of domestic wastewater is low, thus nitrification is crucial for proper denitrification. The amount of dissolved oxygen is also important when dealing with denitrification. Plant uptake is the primary mechanism for reducing nitrogen in FWS wetlands. The removal efficiency of all wastewater wetlands vary between 40 and 50%. This depends on whether the wetland is being used for primary treatment or secondary treatment. It has been found that wastewater wetlands may be unable to meet primary nitrogen requirements and that the system may better suited by coupling with a traditional wastewater treatment plant (Vymazal, 2006).

MECHANISM OF PHOSPHORUS REMOVAL

Another important nutrient that causes eutrofication in water is phosphorus. Removal of phosphorus tends not to be as high as nitrogen removal in wastewater wetlands. This is because wetlands do not provide the direct metabolic pathway to remove phosphorus. Wetlands use physical, chemical, and biological means to reduce phosphorus (DeBusk, 1999b). Phosphorus exists as phosphates as inorganic and organic forms. The predominant form is in the form of orthophosphate which can be used by algae and macrophytes. Inorganic phosphorus can also be found as polyphosphates. Organic forms include phospholipids, nucleic acids, nucleoproteins, and phosphorylated sugars. These forms are primarily known as easily decomposable phosphorus and there other forms called slowly decomposable organic phosphorus which contains phytin (Vymazal, 2006). The major phosphorus transformations in wastewater wetlands are done by physical/chemical means and biological means. Figure 5 below outlines the major phosphorus transformations in a FWS wetland.

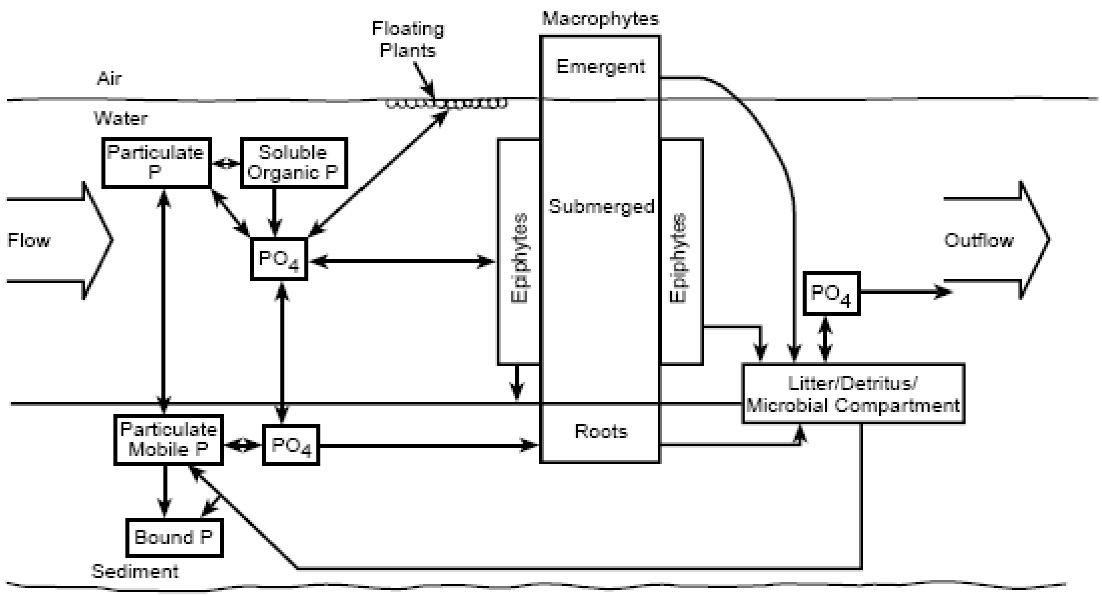

Figure 5 – Phosphorus transformations in a FWS wetland (EPA, 1999).

The major removal of phosphorus is done by uptake from plant roots. The absorption through leaves and plant parts are usually very low and thus macrophytes account for most of removal at the beginning of the growing season. The storage of phosphorus in plants varies between the type of plant and storage below ground is usually longer than storage above ground. Phosphorus is released in portions at varying times throughout the year and is cycled throughout the wetland. Phosphorus is also released after a plant dies and begins to decay. The decaying plant matter above ground release phosphorus into the water while decaying roots secrete phosphorus into the soil. Another important chemical transformation is soil adsorption and precipitation. This process involves soluble inorganic phosphorus moving from the pores in the soil media to the soil surface. With increased clay content the soils adsorption qualities increase. The problem by physical and chemical removal in wastewater wetlands is that the wetland only accounts for storage in soil media or in plant tissue. Each of these will eventually reach capacity and phosphorus removal will cease until the two are replaced. The other mechanism for removal of phosphorus is by biological means but this process still does not allow for much storage. The uptake of phosphorus by microorganisms is rather fast because bacteria, fungi, and algae are able to multiply quickly. The drawback is that they are unable to store large amounts of phosphorus (Vymazal, 2006).

The extent at which phosphorus can be removed or stored is dependent on the type of wetland being used. There are limiting ways to remove and store phosphorus. These ways include sorption, storage in biomass, and formation of new soil media. The long term solution to removing phosphorus is through peat/accretion but will only be effective if there is lots of biomass. Adsorption of phosphorus through soil media is mostly used in VSB wetlands but the type of media will determine how well phosphorus is stored. In FWS wetlands the uptake from free floating macrophytes is more important but these plants must be harvested and replaced to maximize phosphorus removal. Removal of phosphorus by biological means is more of a temporary solution since the phosphorus is released in the water once the organism begins to decay. Typical phosphorus removal is in the 40-60 percent range (Vymazal, 2006). It is important to recognize the processes at work and also realize that wastewater wetlands are not capable of meeting primary phosphorus removal standards.

MECHANISM OF PATHOGEN REMOVAL

Major concerns with wastewater wetlands are their ability to remove pathogens of helminthes, protozoans, fungi, bacteria, and viruses. There have been reports that wetlands reduced total coliforms by 57 percent, and fecal coliforms by 62 percent. There have also been reports of 98 percent reduction of giaridia and 87 percent reduction of cryptosporidium. The main process that are involved with pathogen removal is sedimentation. Sediments of wetlands tend to accumulate as vast amounts of coliforms and bacteria. It has been found that river mud contains 100-1000 more times more fecal coliforms than the surface water. This is also similar to salmonella which 90 percent of it accumulates in sediments. These sediments also give some bacteria the ability to survive longer. Viruses tend to attach to colloidal material which takes longer to settle out and eventually settle out in a loose layer above sediment. This layer can be disrupted from human activity or natural storm events which could cause the pathogens to enter the water column. Another way to filter out pathogens is thought to be through the root structure of plants in wastewater wetlands. In a study done by Mohammad Karim he tested whether sedimentation played a significant role in reducing pathogens in wetlands. He observed that there were not large differences in the amount of fecal coliforms and coliphages in the water column and sediments. The attachment to the root structure played a larger part with these pathogens. The report found that giardia and cryptosporidium had concentrations two to three times larger in sediments than in the water column. A multispecies wetland showed 73 and 58 percent removal of giardia and cryptosporidium and a duckweed wetland showed 98 and 89 percent prospectively (Karim et al., 2004). Wastewater wetlands offer promise of the possibility of removing pathogens. Removing pathogens from the water table does not mean that pathogens are gone for good. It is possible that pathogens can reenter the water table but further work must be done on pathogens survivability in wetlands.

MECHANISM OF METALS REMOVAL

There are some metals that are required for plant and animal growth but these are in very small amounts. These nutrients include copper, selenium, and zinc. These micronutrients are toxic at higher concentrations but other metals can be toxic at even at low concentrations. These metals include cadmium, mercury, and lead which are typically found in industrial wastewater. These toxic metals have no known benefit but can lead to health hazards in humans. Removal of metals in wastewater wetlands occur by plant uptake, soil adsorption, and precipitation. The ability of plants to uptake metals depends on the type of plant and type of metal. There are some types of plants which are capable of storing large amounts of metals in plant biomass and in its roots (DeBusk, 1999b). One such plant is duckweed which is known to store large amounts of cadmium, copper, and selenium. The metals that pass by the root structure tend to accumulate on the structure of the root rather than being absorbed by the plant. Wetland soils are also sources into which can trap metals. Metals including cadmium, copper, nickel, lead, and zinc form insoluble compounds when interacting with sulfides under anaerobic conditions in the soils of wastewater wetlands. This minimizes the ability of these metals to resolubilize under anaerobic conditions. Through a process called chemisorption, metals such as chromium, copper, lead, and zinc form strong chemical complexes with the organic material that is present in the soil and water. Furthermore, the metals chromium and copper can be chemically bound to clays and oxides and allowed to settle out (EPA, 1999). In a study done by M.A. Maine studied metal uptake in a wetland containing of several plant species. The wetland had 80 percent of cover by Eichhornia crassipes (water hyacinth), 14 percent cover by Typha domingensis (cattail), and four percent of Panicum elephantipes (elephant panicgrass). The wetland removed 86 percent of chromium and 67 percent of nickel. The concentration of zinc was below 50 micro grams per liter in most of the samples. Iron sulfide precipitation helped in reducing the iron content by 95 percent. A larger wetland and a smaller wetland were tested where the metals in the larger one were retained by macrophytes and retained by sediment in the smaller wetland (Maine et al., 2006). Wastewater wetlands show promise for removal of metals but further research is needed in this area.

CASE STUDY

The amount of removal of materials depends on the type of constructed wetland being used. In a study done by Bilal Tuncsiper three pilot plants were constructed. A horizontal-subsurface flow (H-SSF), surface flow (SF), and a free water surface flow (FWS) were constructed and evaluated by treating wastewater from the Pasakoy Advanced Biological Wastewater Treatment Plant (PABWWTP) in Turkey. Figure 6 below shows the three different types of wetlands used in the study.

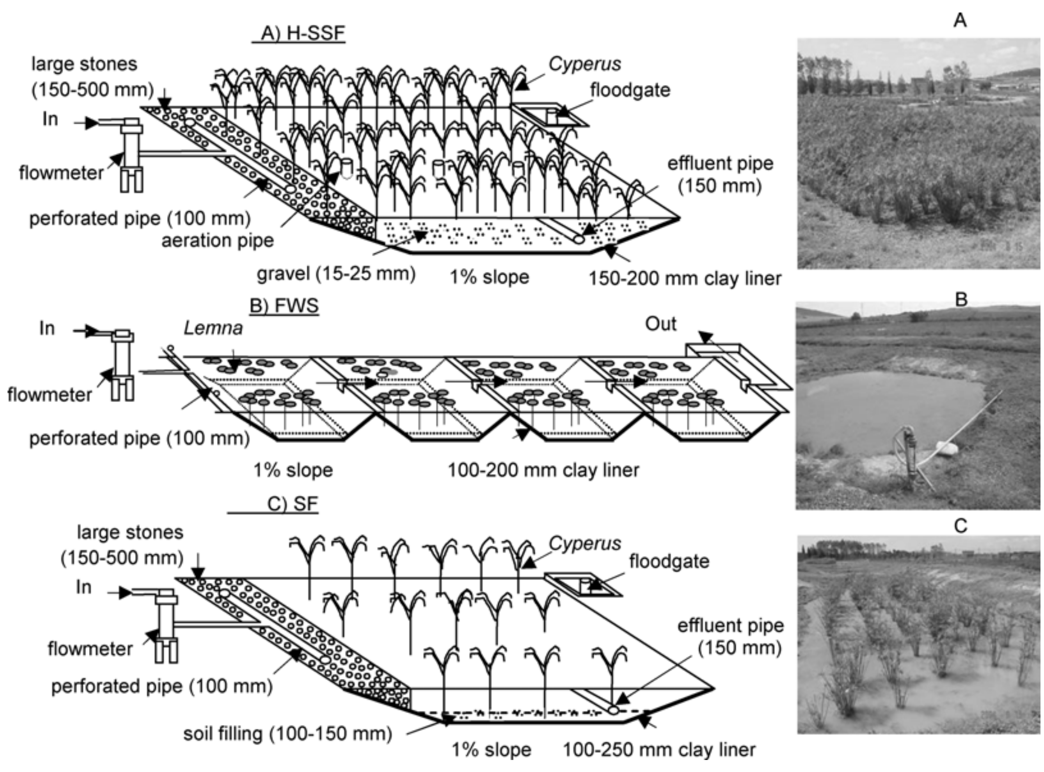

Figure 6 - The three different types of constructed wetlands used in the pilot study (Tuncsiper, 2007).

The average ammonia-nitrogen removal ranged between 49 to 52 percent for all three systems. The SF system had the highest nitrate removal of 58 percent thus telling that this had the highest denitrification rate. The H-SSF plant had the highest removal efficiency of phosphorus of 60 percent most likely due to the gravel substrate. This decrease was still not able to meet standards for drinking water or irrigation water. All systems saw removal of 94 percent of fecal coliform bacteria. Nutrient removal of ammonia nitrate, nitrate, and phosphorus was higher for all plants in the summer except for fecal coliform removal. The results show that contrasted wetlands can be used as a secondary treatment of the primary treated wastewater (Tuncsiper, 2007).

CONCLUSION

Constructed wastewater wetlands have shown that there is capability of treating different kinds of wastewater. Recent research has focused on using constructed wetlands to treat domestic wastewater. The contaminants being removed include suspended solids, organic matter, nitrogen, phosphorus, pathogens, and metals. The removal of suspended solids is mostly done by flocculation/sedimentation and filtration/interception. Typical suspended solids concentrations range between 3 and 5 mg/L for constructed wetlands. The removal of organic matter is done by physical and biological means. Physical removal is done by sorption and volatilization and biologic removal by aerobic, anaerobic, and anoxic organisms. Removing nitrogen is done by a number of processes, the major one by nitrification and denitrification. Wastewater wetlands have the ability to reduce nitrogen by 30 to 50 percent. Phosphorus removal is carried out by plant uptake, adsorption/precipitation, and by biological storage in microorganisms. Typical amounts of phosphorus removal are in the range of 40 to 60 percent in wastewater wetlands. The slow moving water in constructed wetlands enable pathogens to settle out and thus wastewater wetlands are capable to removing high percentages of fecal coliform, giardia, and cryptosporidium. The ability of wastewater plants to use plant uptake, soil adsorption, and precipitation help in the removal of metals in wastewater. By selecting proper plant species, wastewater wetlands can achieve relatively high percentages of metal removal. By understanding how contaminants are removed proper decisions can be made for how to implement constructed wastewater wetlands. Research has found that wastewater wetlands are successful in removing contaminants but sometimes may not be the best option for primary treatment standards. Constructed wetlands make a good secondary method for treating domestic wastewater. Constructed wastewater wetlands offer aesthetic pleasing environments which function on less complicated technologies that are successful in removing many different types of contaminants.

REFERENCES

DeBusk, William F. (1999a) *Wastewater Treatment Wetlands: Contaminant Removal Processes.* Soil and Water Science Department, University of Florida. **SL155**.

DeBusk, William F. (1999b) *Wastewater Treatment Wetlands: Applications and Treatment Efficiency.* Soil and Water Science Department, University of Florida. **SL156**.

Interstate Technology & Regulatory Council (2003*) Technical & Regulatory Guidance for Constructed Treatment Wetlands*. United States Environmental Protection Agency.

Karim, Mohammad R.; Manshadi, Faezeh D.; Karpiscak, Martin M.; Gerba, Charles P. (2004) The Persistence and Removal of Enteric Pathogens in Constructed Wetlands. *Water Research*, **38**, 1831-1837.

Lorion, Renee (2001) *Constructed Wetlands: Passive Systems for Wastewater Treatment*. National Network of Environmental Management Studies. Washington State University.

Maine, M.A.; Sune, N.; Hadad, H.; Sanchez, G.; Bonetto, C. (2006) Nutrient and Metal Removal in a Constructed Wetland for Wastewater Treatment From a Metallurgic Industry. *Ecological Engineering*, **26**, 341–347.

Manios, T.; Stentiford, E. I.; Millner, P. (2003) Removal of Total Suspended Solids from Wastewater in Constructed Horizontal Flow Subsurface Wetlands. *Journal of Environmental Science and Health*, Part A**,** **36**, 1073-1085.

Murphy, Sheila (2007) *General Information on Solids*. City of Boulder/USGS Water Quality Monitoring. Accessed 07 November 2007. <http://bcn.boulder.co.us/basin/data/COBWQ/info/TSS.html>

Tuncsiper, Bilal (2007) Removal of Nutrient and Bacteria in Pilot-Scale Constructed Wetlands. *Journal of Environmental Science and Health*, Part A, **42**, 1117-1124.

United States Environmental Protection Agency (1999) *Constructed Wetlands Treatment of Municipal Wastewaters*; **EPA/625/R-99/010**; Cincinnati, Ohio.

Vymazal, Jan (2006) Removal of Nutrients in Various Types of Constructed Wetlands. *Science of the Total Environment*, **380**, 48-65.