Restoration and Reclamation Review
Student On-Line Journal
Vol.2, No.4, Spring 1997
Department of Horticultural Science
University of Minnesota, St.Paul, MN

Anatomy of a Constructed Wastewater Wetland

Veronika Phillips

Introduction

The use of constructed wetlands for wastewater treatment allows the purification of wastewater in a manner that incorporates natural processes. Construction of artificial wastewater wetlands is a relatively simple and inexpensive process. It is possible to create a system that processes the wastewater in such an efficient manner that there is low to zero flow out of the wetland into a receiving body of water such as a river, lake or ocean. Constructed wetlands can meet local performance standards for pollution removal, especially when used in conjunction with conventional systems. Through sensitive design, constructed wetlands may become fully functioning ecosystems that can contribute to the habitat needs of aquatic species.

Historic Perspective

Natural wetlands have been the recipients of domestic wastewater since the first sewage collection systems were installed in the early part of this century. As a result of the Clean Water Act in 1972, the Environmental Protection Agency started monitoring the water quality in some the 324 wetlands receiving wastewater used throughout the United States (Kadlec 1996). The information gathered from these analyses showed the potential for wetlands as natural water purifiers. Researchers in Germany began the first scientific studies on the use of wetlands for wastewater treatment in the early 1950's. It would take another 17 years before United States researchers in Chapel Hill, North Carolina began a five year study using a combination of constructed estuarine ponds and natural salt marshes for the removal of municipal waste water (Kadlec 1996). In 1973, the first fully constructed wetland consisting of a series of constructed marsh, pond and meadow was built in Brookhaven, New York (Kadlec 1996). The use of constructed wetlands for wastewater treatment, especially at the residential scale, has not been exploited to its fullest potential. Hopefully, as the public becomes more aware of the opportunities these systems provide increased use will follow.

Constructed Wetland Systems

There are two types of constructed wetlands that are being built today. The first of these is a surface-flow wetland and the second is a subsurface-flow wetland. Both of these systems use many of the same concepts, the major difference is the location of the water during treatment. In surface-flow wetlands the water moves above the root zone, through the plant stalks (Figure 1a).

According to Jenssen (1991), purification of the wastewater occurs through the microbial interactions on the plant stalks, as well as through reactions in the water and the upper sediment zone.

In a subsurface-flow system, the water moves horizontally or vertically through the root zone of the plants within a substrate of sand and gravel (Figure 1b and 1c). Microbial growth on the plant roots, chemical processes, and filtrations of the substrate itself combine to provide the water cleansing properties in this system (Jenssen 1993). In both systems organic matter and nitrogen are removed by biological mechanisms, while the soil media adsorbs phosphorus.

Area Requirements

According to Moshiri (1993), the expression of square feet per gallon per minute (sf/gpm) is used in expressing the area required in a constructed wetland. Four considerations are used to calculate the area required design flow rate (generally, ranging from 0.1 to 1.0 feet/square), type of waste to be removed, concentration of waste in the wastewater and pollutant discharge requirements (Moshiri 1993).

Hydraulic Profile

A hydraulic profile is used to view a cross-section of the water levels through the constructed wetland cells (Figure 2). The cost-effective means of moving water through a

constructed wetland is by gravity. Pumps may have to be used to bring wastewater to the constructed wetland from a primary treatment unit, carry the treated water from the constructed wetland or return ground water leakage back to the wetland (Kadlec 1996). The use of pumps is generally avoided in an effort to keep construction costs down.

Compartmentalization

Site constraints and maintenance requirements determine the number of cells in a constructed wetland. Uneven topography with steep slopes may require the use of terraced cells. According to Kadlec (1996), all constructed wetlands should have at least two cells that can operate in parallel to allow for cell resting, rotation of flows or maintenance. Water depth in constructed wetland cells is generally less than 18 inches deep. Moshiri (1991) states that one system had varied water depths of 6 to 18 inches for treatment areas and 2 to 10 feet for wildlife habitat and increased sediment trapment.

To discourage channelization of from points of inlet to points of outlet it is important to have a continual grade on the floor of the cell. Cell slope is between 0-3% (Conley 1991). A continual bottom grade is difficult to maintain once vegetation becomes established. In an effort to provide even flow, deep zones of unvegetated cross ditches of at least 1 meter provide a low resistance path for the lateral movement of wastewater (Kadlec 1996). These deepwater areas are prone to growth of duckweed which provides a food source for waterfowl. Kadlec (1996) recommends four general guidelines when designing a constructed wetland cell: avoid blind spots in corners, provide flow straightening berms interior to an individual cell, reestablish flow distribution at intermediate points in a flow path and maintain bottom uniformity during construction and startup.

Berms

Berms regulate and contain water within specific flow paths. Exterior berms should be large enough to control overflow in the event of a storm and aging effects such as sediment and plant accumulation. The bottom of the constructed wetland as well as the exterior berms must be constructed with cores of impermeable materials, such as clay or plastic liners to prevent leakage

A 2:1 slope is typical in berm construction, but for shallower constructed wetlands a 10:1 or 20:1 slope can be used to create a habitat diversity (Kadlec 1996). Interior berms that are used for flow straightening within a cell are smaller and do not need an impervious core.

Occasionally, berms may have to be repaired from damage by burrowing muskrats (Kadlec 1996). Muskrat damage may cause leakage of wastewater from the wetland and result in possible contamination of the surrounding soil or bodies of water.

Control Structures

Inlets control the flow of wastewater from the septic pre-treatment into the constructed wetland. An important property of the inlet is the degree to which it promotes sheetflow in an even distribution across the width and depth of a constructed wetland. The design of the inlet is in response to the size of the constructed wetland. In small systems a single-point discharge is adequate. In a larger system a concrete channel with notched weirs (water control device) would be located along the entire width of the system (Kadlec 1996).

Outlets maintain sheetflow distribution, water level and monitor flow and water quality. The outlet design can vary between a very simple and inexpensive design such as a pipe embedded in a berm, to a more expensive electronically monitered system of wier controls. According to Kadlec (1996), control of water level is important for three reasons: plant growth, allowing adequate time for wastewater to be treated (hydraulic loading time) and the opportunity for drainage when maintenance is required.

Occasionally, beaver may cause system dysfunction by building dams near wastewater inlets. This damage may result in increased residence time of the wastewater, causing low oxygen conditions from the stagnant water.

Plants and Planting

Emergent wetland plants with regenerative capabilities are used in constructed wetlands. The general criteria of these plants are that they are fast growing, have high lignin content, and are adapted to variable water depths. The three most common genera are *Typha*, *Scirpus* and *Phragmites* (Conley, 1991. According to Kadlec (1996), planting densities range from 400 to 4000 plants per acre.

A main concern for plant survival is making sure that the water levels are correct. It is important to insure adequete water depths for root growth. It is important that the depth of the water be increased slowly to allow for morphological adaptations that are needed for survival (Kadlec 1996).

The treatment capabilities depend on the cyclical process of the plant providing oxygen for aerobic bacteria and the plant structure providing a substrate for both anaerobic and aerobic bacteria. The process is not complete without the build-up of dead plant detritus on the wetland floor. This material provides a source of organic matter that contributes to the cyclic process. Kadlec (1996) states that a constructed wetland takes 1 to 5 years to support this internal nutrient cycling. One to two year old plants are used to provide quicker establishment and operation of the constructed wetland. As in nature, high plant diversity is preferred in constructed wetlands. Plants that are used for primary treatment are most likely going to be monocultures, but in systems that are used as the final stages for wastewater treatment, plant diversity is possible.

Herbivores such as muskrat, geese and army worms have been known to eliminate between 5 to 83% of emergent plant biomass resulting in open areas of water for weed colonization and algal blooms (Kadlec 1996).

A Comparison of Constructed Wetlands to other Natural Systems and Conventional Sewage Treatment Facilities

A constructed wetland and a infiltration field wastewater treatment system have comparable initial construction costs and have minimal maintenance costs. Onsite infiltration systems have been the preferred choice for wastewater treatment in single households and small communities. According to Kadlec, the cost of a small scale individual domestic septic system with an infiltration field is approximately $2,000 to $5,000 for start-up costs. Moshiri (1993) provides a cost of $3300 for a small scaled individual domestic constructed wetland for a three bedroom house. This price includes the septic system necessary for pretreatment, a pump and its associated electrical costs. A limiting factor in using an infiltration field instead of a constructed wetland would be the requirement of permeable, unsaturated soils and that it is a technology limited to small systems. It is important to remember that even though a constructed wetland can handle larger volumes of wastewater, a sufficient quantity of land can be a limiting factor.

Other land application systems used for the treatment of wastewater in small towns have been faculative ponds, overland flow systems and unharvested floating aquatic systems. These systems require receiving water such as a natural or constructed wetland.

Historically, high rate land application systems have been the most cost effective in wastewater treatment for small to medium sized towns. In some instances receiving water cannot handle the discharge resulting from a land application system and a constructed wetland would be used as the receiving waters (Kadlec 1996).

Generally, constructed wetlands have been used in conjunction with conventional systems in cleaning the wastewater of medium to large cities. According to Kadlec (1996), to clean 3786 m^3/d, a conventional sewage treatment system would cost $4,112,000 to construct with an operation and maintenance cost of $156,000 per year and would use 5 acres of land. In a constructed wetland, 90 acres of land would be required, but the total construction cost would be $3,664,000 with maintenance and operation costs of $45,000 per year. Cost of constructed surface-flow wetlands is between $4,000 and $40,000 per acre. The cost of a subsurface flow wetland is between $40,00 and $80,000 per acre. The advantage of conventional wastewater treatment systems (those that are not land intensive) is that they remove pollutants at faster hydraulic loading rates of 1 to 2 days, require a smaller area, and more importantly have a controlled environment that is not susceptible to climatic events (Kadlec 1996). A great disadvantage is the increased maintenance costs and the large quantities of nonrenewable fossil fuel energy they require for treatment. Natural systems are more susceptible to climatic events such as wind, rain, insects, and floods and have lengthy hydraulic loading times of 3 to 200 days. Although constructed wetlands do have limitations, they can provide opportunities for wildlife habitat, community enhancement and low to non-existent discharge into lakes, streams and oceans due to evapotranspiration (Jennsen 1993).

Cleansing Capabilities

According to Moshiri (1993), the BOD^5 (five-day biochemical oxygen demand) is the most frequently used parameter to measure constructed wetland performance. The BOD^5 integrates the processes of organic and chemical oxidation occurring in a water sample containing solid and dissolved pollutants. Data analysis of 84 constructed wetlands provided an average BOD^5 of 10.5 mg/L. A BOD^5 of 5-30 mg/L is generally used as a criterion for performance standards. Occasionally, oxygen levels will be insufficiently low due to an inbalance between atmospheric aeration and the high amounts of BOD and ammonia entering the system from wastewater. These low oxygen levels decrease the wetland plants cleansing capabilities.

In the same study of 84 constructed wetlands, suspended solids (SS) were removed to 15.3 mg/L. The general requirement for total suspended solids removal is 10-30mg/L (Moshiri 1993). A difficulty with the settling process in a constructed wetland is the possibility of pore space blockage in subsurface flow wetland and to elevational increases in the bottom of the surface flow wetland. If sedimentation is slow enough, adaptations of the root zone can take place and the system will remain functional. According to Kadlec (1996), a 20 year old constructed wetland used for municipal wastewater treatment has never had to be serviced for solids removal. In a situation were sedimentation rates are too high for plant adaptation, blockage may occur and a settlement pond may be necessary as a pretreatment for the wastewater. Resuspension of solids may occur by feeding and nesting fish, but this can be controlled by draw-down or freezing of the wetland cell. Resuspension by wind can also be a problem, but is generally controlled in a fully vegetated wetland whose litter and root mats will stabilize the sediment.

Nitrogen and Phosphorous removal is dependent on system design, retention time and oxygen supplies, all of which can be manipulated to control removal. Acceptable levels for NH3-N is 4.2mg/L. In the study of the 84 constructed wetlands, of the 55% measured for NH3-N, levels of 1-8mg/L were found (Moshiri 1993). If phosphorous removal is a design issue then adequate time in a settling pond should remove much of the phosphorous.

Although constructed wetlands are capable treating the biochemical oxygen demand and reducing nitrogen loads, if the soils are not properly aerated, increased water depth can lead to overloading of oxygen-demanding constituents and highly reduced sediment conditions, which can lead to plant stress and reductions in BOD removal and ammonia nitrogen (Kadlec 1996).

Constructed Wetlands Under Winter Conditions

Jenssen (1991) tells us that effluent entering the constructed wetland is seldom below 5° C. With adequate insulation by snow cover, ice and natural plant cover a constructed wetland is fully operational under freezing temperatures. Kadlec (1996) notes that by dropping the water level to create a pocket of air between the ice and the water will ensure that complete freeze-through will not occur and that biological activity of the plants will be maintained and the system fully operational throughout the winter. Although decomposition may slow down in the winter, ammonium nitrogen will accumulate under the ice and will remain available until spring when plants can utilize it for spring growth.

References

Conley, Lucy, et al. (1991) An Assessment of the Root Zone Method of Wastewater Treatment. *Research Journal of the Water Pollution Control Federation*. 63.3:239-247.

Dobberteen, Ross. (1991). Use of Created Cattail (*Typha*) Wetlands in Mitigation Strategies. *Environmental Management* 15.6: 797-808.

Jenssen, P.D., et al. (1993). Potential use of Constructed Wetlands for Wastewater Treatment in Northern Environments. *Water Science Techniques* 28.10: 149-157

Kadlec, Robert and Robert Knight. (1996). *Treatment Wetlands*. Boca Raton, Florida: CRC Press, Inc.

Moshiri, Gerald. (1993). *Constructed Wetlands for Water Quality Improvement*. Boca Raton, Florida. CRC Press, Inc.

Reed, Sherwood. (1992). Constructed Wetland Design---The First Generation. *Water Environment Research*. 64.5:776-781.