Focus 10,000

Published October/November 1998, 2000 in Focus 10,000

Constructed Wetland Treatment Systems

Rich Axler (Research Associate, Natural Resources Research Institute-UMD)
Barb McCarthy (Research Fellow, Natural Resources Research Institute-UMD)
Jerry Henneck (Assistant Scientist), Natural Resources Research Institute-UMD
Dave Gustafson (Engineer, Dept. of Biosystems and Agricultural Engineering,UM-St. Paul).

This is the fourth in a series of articles on alternative wastewater treatment systems in Minnesota.

Historically, constructed wetlands have been used world-wide for over 30 years, in both warm and cold climates. In Minnesota, constructed wetlands are being used to treat wastewater from both residential and commercial establishments. In 1995, research sites were established in northern Minnesota at the Northeast Regional Correction Center (NERCC) near Duluth, and in southern Minnesota at Lake Washington near Mankato. The research is in the third year of testing alternative treatment technologies for individual homes, including constructed wetlands. The ability of constructed wetlands to work successfully during the winter months is being evaluated through this research effort.

Figure 1. A close-up view of a wetland treatment system by NRRI researchers Rich Axler and Jerry Henneck at the Lake Washington research/demonstration site near Mankato.

How do they work?

A constructed wetland system treats wastewater by a variety of physical, chemical and biological processes that also occur in natural marshes. As wastewater moves through the wetland, solids are removed through physical filtration, settling and decomposition. Organic matter (measured as *Biochemical Oxygen Demand = BOD*) is reduced by being consumed by bacteria and other microbes (*biodegradation*), both aerobically (oxygen supplied by the atmosphere and by plants growing in the wetland) and anaerobically (when there is no oxygen present). Nutrients that may cause eutrophication such as phosphorus and nitrogen may also be reduced. Phosphorus removal is largely due to chemical adsorption (essentially an ion exchange) to plant litter and to the gravel substrate. Iron-rich materials are particularly good at P-removal.

Nitrogen removal, on the other hand, is much more complicated and begins with bacteria decomposing proteins and other forms of organic nitrogen to ammonium. This ammonium can then be converted to nitrate by certain aerobic bacteria via a process called *nitrification*. A sewage treatment plant requires heavy-duty aeration pumps or pure oxygen injection to enhance this conversion. In a marsh, or treatment wetland, nitrification is accomplished by oxygen diffusing from the atmosphere (if there is open water) or by certain wetland plants. Cattails, reeds, bulrushes, wild rice, pickerel weed, arrowhead, and many other species survive being submerged by actually pumping oxygen down to the roots. Excellent N-removal can be obtained by allowing the nitrified (high nitrate) water to then become anaerobic again. This facilitates the growth of denitrifying bacteria that convert the nitrate to harmless nitrogen gas (N_2), which makes up almost 80% of the air we breathe. The root zone, therefore, provides an excellent habitat for the diverse groups of aerobic and anaerobic bacteria that are needed to treat wastewater. Although the plants do take up some of the nutrients in the wastewater, including nitrogen and phosphorus, this is typically a small fraction of the total waste load.

Two types of constructed wetlands systems are most commonly used: the free water surface (FWS or open water) and the subsurface flow (SSF) systems. The open water wetlands resemble wetland ponds. Wetland plants grow from the soil bottom of the wetland and water moves through the system at the surface. Water evaporates off the surface and atmospheric oxygen re-aerates the surface while deeper water and sediments remain anaerobic. The direct exposure to the air typically provides more oxygen than do the plants alone, and so these systems can be better at nitrification. In Minnesota and elsewhere, these types of wetlands are not typically used for individual homes, but rather for larger, municipal-type systems because the open water is a public health hazard. They also typically require more space than SSF's for the same level of treatment.

Subsurface flow wetlands are constructed so that the effluent stays below the surface of the wetland. Treatment processes are again a mixture of aerobic, with oxygen supplied to micro-sites largely by plant roots, and anaerobic within the pore water in the rock media. Besides minimizing human contact, keeping the water subsurface also eliminates odors and potential mosquito habitat. SSF wetlands are the type being used in Minnesota for small wastewater flows. A variety of hybrid systems including vegetated sand/gravel filters (also called a *vertical flow constructed wetland*) have shown promise for even higher performance.

Parts of a Constructed Wetland

A constructed wetland has four main parts: an impermeable liner, a rooting substrate for the vegetation, wetland plants, and a water-level control structure. The impermeable liner prevents wastewater from prematurely seeping out of the wetland and groundwater from entering the wetland. Although the liner can be fabricated from different materials, 30-mil PVC is a common and reliable product. A thick clay layer is also used for larger systems.

The rock media at the inlet of the wetland, where wastewater enters the wetland from a septic tank, is typically 2 to 3 inch sized rock. The piping that carries sewage into the wetland is buried within this coarse rock so that the incoming wastewater is spread across the width of the wetland. Smaller-sized pea rock (1/4 to 1/2 inch) is used in the remainder of the lined excavation to a depth of 18 inches. The depth is a tradeoff between being shallow enough for the roots to extend to the bottom of the bed, while providing sufficient volume to prevent freezing problems. The surface of the pea rock is raked level to ensure that plant roots can reach the wastewater below the surface.

Figure 2. The placement of pea rock over limestone in the second-cell of the constructed wetlands at NERCC in the fall of 1995.

The third part of the system is the vegetation. Wetland plants are planted directly into the pea rock (or in a mulch layer spread over the pea rock) at the surface with cattails, bulrushes, reeds, and other water-loving plants. An important function of wetland plants is to transport oxygen through its root system into the wetland, supplying oxygen to bacteria growing on plant roots to improve the decomposition of organic matter and convert ammonium to nitrate. The plants also provide some insulation to prevent the wetland from freezing during the winter months and act as a snow fence to accumulate a blanket of snow that insulates the system.

The control structure is the last component of the wetland, where effluent flows out of the wetland and into the soil for final treatment. The control structure regulates the depth of wastewater in the wetland and is typically set to maintain the wastewater 1 to 2 inches below the top of the bed. It should also provide for flow measurement and sampling.

Design Considerations

At the NERCC research site, replicated subsurface flow wetlands were constructed to treat the flow (250 gallons/day) from a typical single-family home. The wetlands are a two-cell system, with each cell having an area of 400 square feet (total area 800 square feet). Our cells are approximately square (L:W = 1), but a length to width ratio of up to about 10:1 is often used. A high ratio can lead to ponding which would “short-circuit” the subsurface treatment and too low a ratio (wider than long) can lead to uneven distribution of water down the length of the bed. The depth of rock placed in the wetland is 18 inches.

At NERCC, cattails were planted in cell 1 and bulrushes were planted in cell 2, and several ornamental wetland plants were planted in the wetland. It would be easy and Inexpensive to landscape the perimeter of the cells with attractive ornamental plants using the wastewater for irrigation and fertilizer. The upper cells were designed for removal of solids (TSS), organic matter (BOD) and disease-causing organisms (indicated by fecal Coliform bacteria) to a secondary treatment plant standards; the same design criterion as for the other alternative systems at NERCC (see previous Barb McCarthy and Jim Anderson articles). The second cells were designed for additional N-removal and P-removal. Crushed limestone was used as the substrate to improve phosphorus removal. By monitoring the entire system at various points along their length throughout the year, we will greatly improve our ability to predict their performance based on their size and the time of year. A new study by NRRI is just beginning at NERCC which is designed to compare the removal efficiencies of cattails, bulrushes and reeds. The southern site at Lake Washington near Mankato also has two SSF CW's that are single-cell (cattails), 600 square feet in area, and 24 inches deep.

Figure 3. One of the NERCC 2-cell constructed wetland treatment system after the first growing season in 1996.

At NERCC, the wastewater remains in the wetland (both cells) for about 13 days (called the *hydraulic residence time*), before draining into a small drainfield trench. The drainfield is being monitored at several depths below the bottom of the trench to determine if wetland effluent can successfully be dispersed into the soil at higher rates, perhaps with less than 3 feet of suitable soil. Similar studies are being performed using septic tank effluent and peat filter effluent.

A wetland system is typically designed with a slight slope (~1%) along its length in case there would be a need to drain it - however, it is the control standpipe that sets the water level. Surface drainage must be directed away from the system since extra water can overload the system. The discharge of wastewater pollutants can be greatly reduced by the evapotranspiration of water during warm periods- in fact, the effluent may be reduced to a trickle for most of the day. Conversely, rainstorms and snowmelt can flush higher than "average" amounts out of the system and so the excavation walls should be as vertical as possible to minimize rainwater collection.

Overall, on-site wastewater treatment systems, including wetlands, operate more efficiently when septic tank effluent is "timed-dosed" to a system, rather than on-demand, as wastewater is used in the home. This technique allows treatment to be maximized by controlling the flow of wastewater through the system by periodically delivering small doses of wastewater to the wetland. This will require some storage (a water-tight septic tank will suffice) and a pump controlled by a timer.

Treatment Performance

A healthy stand of wetland vegetation is one of the most important factors that influence the overall performance of constructed wetlands. The best time to plant is in the spring or early summer. It will probably take 3 years for plants, like cattails and bulrushes, to become fully established. Plants may be purchased from a number of regional nurseries, or harvested locally after obtaining a permit from the county or DNR. The stems are cut back to about 6 inches and the root-rhizome is planted in a scooped out hole. About 1 plant per 1-3 square feet is reasonable, and by the end of the first growing season you can see that the plants send out subsurface runners that sprout new shoots. Therefore, performance of constructed wetlands in Minnesota may not reach their ultimate performance until the third growing season (1998 at NERCC and 1999 at Lake Washington).

Overall, the constructed wetlands have worked well during the first 2-1/2 years of operation. The best performance of the wetland occurs during the growing season (about May through September in NE Minnesota), with decreased performance observed during winter. Secondary treatment standards" for the removal of solids (TSS) and organic matter (BOD) were achieved for most periods of time. BOD removal efficiency by cell-1 has averaged about 80% in winter and about 90% in summer; cell-2 improved performance further to >95% in summer. Solids removal was generally similar to that for BOD. Fecal Coliform bacteria (indicators of disease-causing organisms) were generally reduced by 96-99% in winter to >99 percent during the snow-free season. The wetlands also have removed nitrogen and phosphorus with efficiencies for both at about 25 - 30% in winter and 65-80% in summer.

Figure 4. A view of the wetlands at NERCC after two years (summer 1997).

Final Dispersal of Wastewater

The effluent from a constructed wetland is routed into the soil for final treatment and dispersal into the environment. The discharge of treated wastewater into surface waters (lakes, streams or wetlands) would require a NPDES (National Pollutant Discharge Elimination System) permit from the Minnesota Pollution Control Agency (MPCA). An NPDES permit for a single-family home is generally not feasible because of operating and monitoring requirements and costs. Several options are, however, available for the final treatment and dispersal of wetland effluent into the soil depending on specific site conditions. These options include shallow trenches, drip distribution, an at-grade system, or a mound system. The design for this component of the system is obviously site-specific depending on soil conditions.

Figure 5. A close-up view of cattails in the constructed wetland at NERCC during the third growing season during a "pathogen" experiment (1998).

The MPCA is currently working to develop *performance-based standards* to determine the level of treatment necessary to safely disperse effluent from alternative treatment systems into the soil. Presumably, the soil at the site may be able to accept more water if it has been pre-treated to remove most of its pollutant load; and so the requirement for at least 3 feet of unsaturated soil might be safely relaxed if the alternative systems are reliable.

Operation & Maintenance

Although a constructed wetland system is a very passive wastewater treatment technology, some operation and maintenance of the wetland is required for the system to operate successfully. The proper functioning of a CW depends on a healthy, dense stand of wetland plants. Additional plantings may be needed during the initial years to fill-in the empty spaces where plant die-offs occur.

Periodic regulation of the control structure may be needed to ensure that ponding of wastewater at the surface does not occur. Wastewater flow to the wetland should be monitored using a water meter or pump run times (event counters) for pumps. Periods of time without sufficient flow may cause the system to dry up or freeze. Conversely, excessive wastewater flows from the home, leaky septic tanks, heavy rains, and rapid snowmelt may lead to long-term reduction in treatment efficiency.

Experience with the winterization of subsurface flow wetlands in northern Minnesota is limited to the last three years, which includes one of the coldest and snowiest winters (1995-1996), a second cold and excessively snowy winter, and one of the warmest winters (1997-98) on record. A layer of straw about 1 ft thick on top of light plastic netting was placed over the CW's wetlands in November of each of the first two winters to maintain heat in the system and to prevent freezing. The following spring, the straw was removed from the wetlands in April so that sunlight could reach the plants. Last winter (1997/1998), no straw was added to find out if sufficient dead plant litter on the surface of the wetland and the snow alone could provide enough insulation. Although the beds did in fact freeze as much as 9 inches deep, the systems never appeared to fail hydraulically. No other difficulties have been encountered with the routine operation of the NERCC CW's since about December 1995.

Figure 6. Cattails at NERCC help to trap and accumulate snow in the winter. The snow helps to insulate wetland systems from freezing.

The research at NERCC and Lake Washington is expected to continue for at least two more years. The goal is to develop wetland design and operational guidelines for single-family homes to facilitate the use of this low-tech system at suitable locations. A copy of the technical report "A Development of Alternative On-site Treatment Systems for Wastewater Treatment: A Demonstration Project for Northern Minnesota" can be purchased for a nominal fee at the Natural Resources Research Institute-UMD at 800-234-0054.