



Constructed WETLANDS FOR Wastewater TREATMENT AND AS Landscape AMENITIES

IN *Rural Communities*

BY GARY AUSTIN

Unlike conventional facilities in cities, sewage treatment in rural towns can take advantage of biological methods. This kind of treatment is less expensive to build, operate and maintain for towns with populations of a few thousand people.

Small communities have the opportunity to take a multi-functional approach to gaining water quality, open space and recreation benefits when they need to expand or upgrade their sewage facilities to meet more stringent quality requirements. Unlike conventional facilities in cities, sewage treatment in rural towns can take advantage of biological methods. This kind of treatment is less expensive to build, operate and maintain for towns with populations of a few thousand people. Conventional sewage treatment requires large inputs of energy and chemicals. These systems are always more expensive than the “natural” treatment systems that

depend on gravity to move water while gravel filters, microorganism and plants clean it (Kadlec, 2009). Design, engineering and assessment of biological treatment of sewage has advanced dramatically in just the last 15 years. Now these methods can be confidently applied to institutions like schools, residential subdivisions as well as small communities, in both warm and cold winter climates.

There are really two wastewater treatment goals. The first is protecting human health and the second is cleaning water enough to discharge into the environment without harming the ecosystem. This article

advocates that the final treatment step employ a pond type wetland to add scenic, wildlife and recreation benefits to the practical need to clean wastewater.

Primary Wastewater Treatment

Biological wastewater treatment requires pretreatment (primary), secondary and tertiary stages. The first stage is very simple. It involves a screen followed by a set of tanks or ponds that let the water sit so the solids can settle out. The solids (sludge) are periodically collected for disposal either in a landfill, an incinerator or methane digester. Sewage lagoons that are common to rural towns can be designed or upgraded to provide primary treatment by providing 108 square feet (10m²) per person. They are not very effective at removing some contaminants nor are they aesthetic elements, but can be upgraded by adding a planted gravel filter dam at the outlet to greatly improve water treatment (Steinmann and Melzer, 2003). Of course, public access to sewage lagoons must not be allowed due to unhealthy water quality.

Primary treatment really is a treatment step, since it improves the water quality by about 50%. Enormous populations of bacteria consume the waste even though there is typically no oxygen or light present. The primary tanks or ponds should have two or more chambers and filters to prevent suspended solids from entering the next stage.

Secondary Treatment

The secondary treatment stage in a biological system uses a constructed wetland to continue the purification process. In this stage removal of biological oxygen demand (BOD) and total suspended solids (TSS) are the two main EPA standards. In raw sewage they can both be 300 mg/L (milligrams per liter) or more, while at the end of secondary treatment they must not exceed 30 mg/L.

Oxygen is used by living organisms and to

breakdown organic and inorganic matter. If the BOD demand is too high, it removes the oxygen that fish and microorganisms in the natural environment need to survive. It is also a rough measure of microbes (including disease causing ones like viruses and E. coli, etc.) in the wastewater. TSS are organic or inorganic particles that make the water cloudy and more importantly serve as sites for harmful bacteria to grow.

There are options for the secondary treatment stage. The common choices are a free water surface flow wetland (FWS), a horizontal subsurface flow wetland (HSF) and a vertical subsurface flow wetland (VSF). The HSF is the most common type in the U.S. but there are many FWS wetlands too. Communities would choose one or another based on local conditions, such as availability of materials, the winter temperatures and the stringency of water quality standards.

Free Water Surface Flow

The free water surface wetland is a series of marsh and open water cells that are heavily planted with wetland plants. As the water flows through the vegetation, bacteria growing on the plant stems and the soil surface clean the water.

Figure 2 shows the plan of a FWS wetland (in addition to two subsurface wetland cells). The FWS and the HSF are equally effective at meeting secondary treatment standards according to recent analysis of hundreds of wetlands (Kadlec, 2009). For secondary treatment public access and perhaps animal access to the water in the FWS wetland must be prohibited. There is also the problem of mosquito control and some problems in locations that experience severe winters. In severe winter areas of northern U.S. and southern Canada the size of the wetland may need to double to achieve the required standards during winter. Monitoring of existing wetlands has established a sizing rule of thumb. The area required for a FWS or HSF wetland to accomplish secondary treatment is 54

to 48 square feet (5-4.5 m²) per person (Cooper, 2009). This equals about one acre for every 850 people the system serves. For accurate wetland sizing matched to the target contaminants or nutrient reduction communities need to consult an environmental engineer.

Horizontal and Vertical Subsurface Flow

Another wetland treatment choice is the subsurface flow (HSF) type where water flows through a bed of gravel planted with cattail, bullrush or other wetland plants. The HSF wetland is about three times more costly to install than the FWS type (unless the FWS is enlarged to accommodate a cold climate).

About 50 square feet of the horizontal flow gravel bed per person served is required to meet EPA secondary treatment standards in summer and winter (Vymazal, 2005). The HSF wetland is less sensitive to cold weather than the FWS and is easier to insulate. A Minnesota HFW is insulated with 6" (15 cm) of mulch to protect it from freezing at temperatures as low as -45°F (Kadlec, 2009). In Norway HSF systems preceded by a buried bio-filter have proven to be very effective (Jenssen et al., 2005).

In the subsurface flow wetland there is no standing water on the surface, so there is no odor or contact hazard, but, like the FWS wetland, the bed is densely planted making it an open space feature. The water flows slowly through the gravel that is 12"-18" deep. Beneficial bacteria growing on the gravel and roots consume many contaminants in the water. Several factors are critical to the effectiveness of subsurface flow wetlands. The plant roots must reach all the way to the bottom of the bed. If they do, then the amount of ammonia removed will be greatly increased (Vymazal, 2005). If water can flow below the roots the amount of ammonia can actually increase. The horizontal subsurface flow wetland is very effective at reducing biological oxygen demand and total

Constructed Wetlands

suspended solids and moderately able to convert nitrates to nitrogen gas but is ineffective at converting ammonia to nitrate and removing phosphorus. Secondary treatment can be accomplished if the water moves through a gravel bed for two days. Three days of residency time is generally required to achieve the maximum removal of pathogens.

There are two kinds of subsurface flow wetlands (Figure 1). In one the water flows horizontally through the gravel bed while in the other the water drains vertically through the bed. Either method can be used to meet secondary treatment goals but in combination they begin to achieve tertiary goals too.

The vertical subsurface flow (VSF) wetland receives periodic doses of pretreated water over its entire top surface. Then the water flows down through the gravel and out of the wetland through a bottom drain. Air replaces water in the gravel pore spaces after it flows through. This system creates an oxygen rich environment where bacteria reduce BOD, TSS and convert ammonia to nitrates. VSF wetlands require only 21.5 square feet (2 m²) per person but they do require energy input, pumps, and more regular attention from an operator (Tuncsiper, 2009).

The VSF wetland is more efficient at removing most contaminants including, BOD, TSS and converting ammonia to nitrates but is ineffective at converting nitrates to nitrogen gas or removing phosphorus. To

take full advantage of the capacity of the VSF wetland to convert ammonia to nitrates and the HSF wetland capacity to convert nitrates to nitrogen gas the two types should be used in combination. Figures 1 and 2 show a configuration that would be very effective for secondary and some tertiary treatment.

Tertiary Treatment

Once the primary threats to human health are addressed in secondary treatment, attention shifts to nitrogen and phosphorus that harm aquatic environments when they are in excess. Ammonia (a type of nitrogen) is toxic to fish and shellfish and should be reduced to 0.26 mg /L if shellfish are present or 1.8 mg /L if they are absent (EPA, 2009). Nitrogen, especially as nitrate is toxic to fish, other aquatic life and people. The standard for drinking water for babies is 1.0 mg/L (10 mg/L for adults).

As illustrated in Figure 2, a sequence of low oxygen (HSF), high oxygen (VSF), low oxygen (HSF) and then high oxygen FWS environments can be provided by a series of wetlands and ponds (Langergraber et al., 2009; Tuncsiper, 2009) to achieve high reductions in BOD, TSS, ammonia, nitrates, coliform bacteria and total nitrogen.

An ammonia removal rate of 97% and a total nitrogen removal of 61% were achieved by a horizontal and vertical subsurface flow wetland configuration similar to that shown in Figures 1 and 2. Note that water from the vertical flow wetland is pumped to the horizontal flow wetland to complete the nitrogen conversion

process (Vymazal, 2005).

Phosphorus is often the most difficult EPA nutrient standard for conventional and biological sewage treatment to meet since a small amount has a large negative impact. Only about 60% of phosphorus is removed by subsurface flow wetlands unless the gravel has high calcium, manganese or iron content, in which case 90% removal is possible (Jenssen et al., 2005). Providing these instead of locally available crushed rock could add significant installation costs. Exacerbating the removal problem is the excessively high loads of phosphorus in raw sewage. The county of Spokane, Washington, banned dishwashing detergent with more than .05% of phosphorus. After one year this has resulted in a 14% reduction in phosphorus in the main sewage treatment plant outflow (Murphy, 2009). Fertilizer is another major source of phosphorus that impacts natural streams and lakes but it is often unregulated.

High Water Quality and Landscape Amenities

In the sequence shown in Figure 2, the marsh and pond stages are the most multi-functional. These constructed wetlands are usually square or rectangular to make engineering calculations and construction simple. However, a little extra effort could greatly improve their aesthetic value (Figure 2) and provide communities with added benefits including:

1. Tertiary polishing of the water

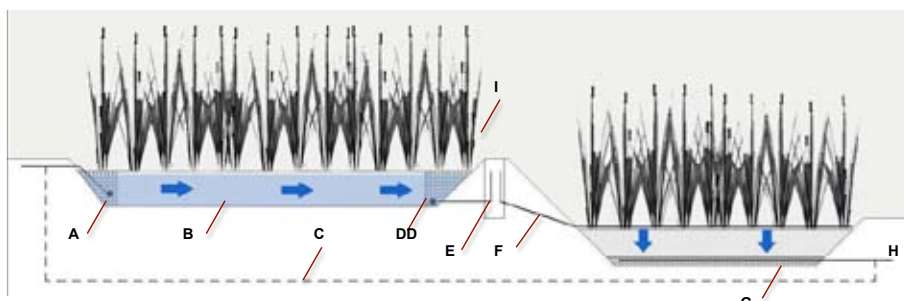


Figure 1 - Horizontal Subsurface Flow Wetland (left), Vertical Flow Subsurface Wetland (right)
 A - Inlet from septic tank; B - Horizontal flow through medium to fine gravel; C - Recirculate 50% of flow from VSF to HSF wetland for denitrification; D - Collection zone, coarse gravel; E - Water level control; F - Intermittent dosing of VSF; G - Water drains vertically through gravel to bottom drain; H - Outflow to free water wetland; I - Dense planting. For the plan view of the HSF and the VSF wetland see Figure 2.

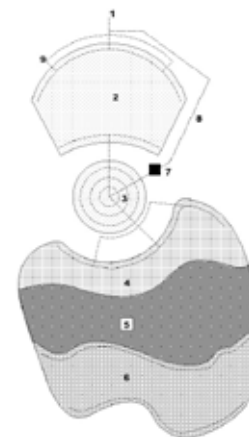


Figure 2 - Wetland System Plan
 1 - Inlet from septic tank or lagoon; 2 - Horizontal subsurface flow wetland; 3 - Vertical subsurface flow wetland (drains vertically through gravel to bottom drain); 4 - Deep marsh (18" deep); 5 - Open water (4' deep); 6 - Shallow marsh (12" deep); 7 - Optional pump; 8 - Optional pipe to return 50% of water from VSF to HSF wetland for denitrification; 9 - Distribution, inlet and outlet pipes. All zones are densely planted except for the open water zone.



- from the subsurface wetlands (especially phosphorus reduction).
2. Water quality that is high enough to support fish and a wide range of aquatic organisms and terrestrial wildlife. This capability along with high visual character attracts people too.
 3. Trails around or boardwalks over the free water wetland shown in Figure 2 would provide opportunities to educate with fish and wildlife interpretive signs, to walk or bicycle and to picnic on the adjacent lands.
 4. Water that is clean enough for human contact and reuse for irrigation and fishing. However, additional purification would be necessary for swimming, reuse in buildings, and especially for drinking.

Compact High Rate Systems

In addition to the subsurface and free water wetlands discussed above, another biological treatment option is available to small communities. This is a high rate, compact treatment system invented by John and Nancy Todd. The proprietary names of the system are Living Machine™ and Eco Machine™. The Todds used the same natural purification process discussed above but utilized a wider range of bacteria, microorganisms, snails and plants in tanks within a greenhouse. The greenhouse keeps air and water temperatures high and allows tropical and subtropical plants to flourish as you can see in the image of the IslandWood Living Machine™ on Bainbridge Island, Washington. This system

requires more energy for water and air pumps, winter heating and lighting. The most recent project designed by John Todd is the Omega Center for Sustainable Living (<http://www.eomega.org/omega/about/ocsl/>) in Rhinebeck, New York. The system is capable of treating 52,000 gallons of wastewater per day using a sequence of septic tanks, a subsurface horizontal flow wetland, an interior aerobic lagoon and a re-circulating sand filter. While installation, operation and maintenance costs are higher for this system than others presented here, the amount of land required is small. The cost is competitive with traditional sewage treatment plants for small communities but eliminates chemical and some energy inputs required of conventional systems. In warm climates, where solar panels are incorporated, or where municipal infrastructure doesn't exist this natural process system is very attractive. The environment inside the greenhouse is very pleasant and can be designed to serve more than the engineering function, as you can see by visiting the Omega Center website.

Conclusion

Biological wastewater treatment systems have improved significantly during the last 15 years. The design and engineering of new systems feature reliable, low cost secondary and tertiary water quality. The landscape characteristics of the systems make them features in rural communities rather than infrastructure blight. The streams and ponds can be integrated into the community park or greenway system to enhance the character and quality of life. ■

About the Author

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