Constructed Wetlands for Natural Wastewater Treatment

Sweetwater Wetlands, a free-surface wetland in Tucson, Arizona.

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Constructed wetlands represent a relatively new ecological engineering approach to treating wastewater using natural systems. The concept developed from observations that natural wetlands remove contaminants from watersheds, inspiring an ecological engineering movement to design systems to meet certain discharge requirements. The first wetland was constructed in East Germany 40 years ago, where "reed bed" systems were used to treat domestic effluent.

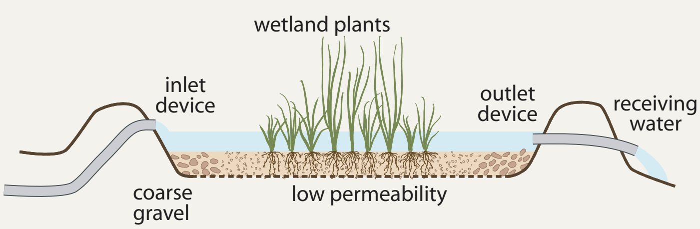
The way natural wetlands, often considered the kidneys of the watershed, reduce organic and inorganic contaminants is similar to the processes at work in constructed wetlands: they accumulate suspended solids, oxidize organic and inorganic compounds, decompose detrital plant material, and remove and discharge nutrients from aquatic plant communities. Both natural and constructed wetlands provide habitat for fish, aquatic invertebrates, aquatic fowl, and other species.

The biological processes that occur in wastewater treatment systems are also like those in constructed wetlands, and include settling, microbial oxidation, anaerobic decomposition, nutrient uptake, nitrification, denitification, adsorption, desorption, and precipitation. But constructed wetland systems use aquatic plants such as cattails and bulrushes and their associated bacterial populations to break down contaminants into relatively innocuous byproducts. Thus, wetlands can effectively treat domestic wastewater, industrial wastewater, animal wastewater, contaminated groundwater, mine waste, urban runoff, and other contaminated waters.

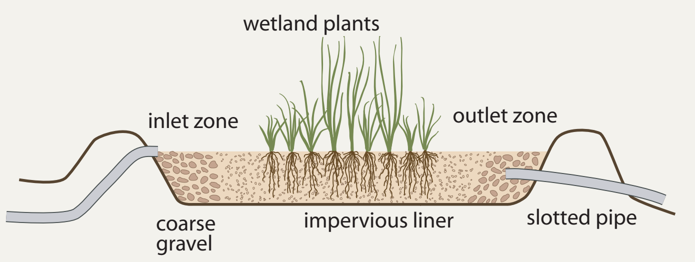
Types of Constructed Wetlands

Free-surface wetlands are usually 1.5 to 4 feet deep with dense populations of floating, submergent (entirely below-surface), and emergent (rooted in water but partly exposed) aquatic plants interspersed with open-water surfaces. They support complex aerobic and anaerobic microbial communities. Those communities in the rhizosphere (the area around the roots) do the work of removing and converting contaminants. Free-surface wetlands usually are lined with geotextile materials or clays. They may require several growing seasons to attain conditions that provide reliable and effective treatment.

Vegetated gravel beds are treatment wetlands with a gravel substrate and aquatic plants, or basically hydroponic systems where plant roots move into the interstices of the gravel. These systems have less ecological value than free-surface wetlands and perform about as well as anaerobic bioreactors. They can be hydraulically loaded horizontally or vertically (see page 29 for discussion of **vertical flow wetlands**); upward vertical feeds are called upflow systems. Although also called **subsurface wetlands** (see page 26), vegetated gravel beds are not technically wetlands because they lack the wide variety of aquatic organisms of true wetlands, and gravels are seldom a substrate of choice in natural settings.



Profile of a typical free-water surface wetland.



Profile of a vegetated gravel or subsurface flow wetland.

Passive System Benefits

The major advantage of constructed wetlands over more conventional treatment systems is their passive operation. For example, in wetlands that receive stormwater, inorganic solids settle, organic solids settle and decompose, oils and petroleum products adsorb to detrital plant material, organisms such as fecal coliform are removed, and metals adsorb and precipitate. All these processes occur without active control or introduction of energy or chemicals, offering considerable economic benefits as well as ensuring long-term reliability of the treatment system.

Periodic maintenance, however, is usually needed. In free-surface constructed wetlands, accumulated settled solids and detrital materials must be removed. The prescribed maintenance is to remove 15 to 20 percent of the material every five to seven years, while leaving most of the active rhizosphere in the wetland. In vegetated gravel beds, the gravels become clogged with roots and solids and the gravel and plants eventually must be replaced.

Photo: Elizabeth Willott

Wetlands systems have proved effective in a wide range of climatic conditions. They operate successfully in Canada and the northern United States, as well as in tropical areas. They work particularly well in hot, arid climates where high temperatures, long days, and aridity create conditions conducive to a thriving ecosystem with accelerated micriobial processes from the introduced wastewater.

Constructed wetlands offer more than just an economical, reliable water treatment system; they assist at the watershed scale in supporting natural systems and compensate for the loss of natural wetlands. They provide habitat for wildlife, open space, and opportunities for environmental education, research, and passive recreation. More than 60 municipal constructed wetlands in the United States take advantage of these benefits.

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Space is a Consideration

Adequate space is obviously an important factor in evaluating the suitability of a constructed wetland. The area needed is usually a function of the amount of flow expected. The design flow for a domestic wastewater treatment system usually assumes a 20-year growth prediction. For urban runoff, agricultural runoff, and silvicultural activities, design flow is a function of the runoff, infiltration, and other hydrologic characteristics of the contributing area. Land targeted for the wetland also should be relatively flat, not an existing natural wetland, and available for a reasonable price. These criteria reduce the use of constructed wetlands to communities and industries with low to medium flows and available space. For example, a wetland that treats domestic effluent to secondary standards requires about 15 to 20 acres per million gallons of flow.

Applications

Urban runoff: The most common use of constructed wetlands is to treat stormwater and urban runoff. They effectively remove sediments and their associated contaminants (such as heavy metals), organisms such as fecal coliform, and hydrocarbons. These systems can be included in landscaped development projects or retrofitted into urban stream and watershed restoration projects. Their passive nature makes them effective in combination with more active best management practices for controlling urban runoff.

Mine waste: Vegetated gravel beds have been very effective in treating mine drainage (see page 20). Underground mining activities and seeps often expose rocks and tailings to oxygen and acidic water, resulting in runoff with high concentrations of toxic metals such as zinc and cadmium. Their passive nature and adaptability to a wide range of climate and geographic locations make constructed wetlands especially suitable for remote mining operations.

Nitrates and perchlorate: Constructed wetlands can treat groundwater high in nitrates from industrial and agricultural activities by converting the nitrates to nitrogen gas. At the Apache Nitrogen Products Inc. (ANPI) constructed wetlands in Arizona (see page 22), groundwater nitrate concentrations of up to 300 milligrams per liter (mg/L) were reduced to under 10 mg/L (the federal drinking water standard), with less than a five-day retention. Although external carbon must be added at ANPI, sufficient carbon normally accumulates from plant decay in the wetlands to support denitrification.

Constructed wetlands also show potential for perchlorate removal. Researchers have isolated an organism that reduces perchlorate to chloride which is similar to those that convert nitrates to nitrogen gas. The organism came from a domestic wastewater wetland in Arcata, California, and likely may be found wherever nitrates are being denitrified.

Hybrids

Hybrid systems incorporating constructed wetlands with conventional treatment systems work well in small community wastewater treatment operations. Pretreatment, as by septic tanks, may be needed to reduce organic and suspended solids from animal waste, domestic waste, or stormwater that can overload, plug, or fill wetlands. Post-wetland water disposal may also be required if the wetland has insufficient infiltration capacity. Hybrid systems also may use vegetated gravel beds, eliminating open water and thereby reducing mosquito habitat.

The Future

The future looks bright for constructed wetland technologies to help address a wide variety of current and emerging pollution problems, such as endocrine disrupters and pesticides. The interest and involvement of experts from a range of disciplines, including hydrology, plant ecology, microbiology, landscape architecture, soil science, conservation biology, vector control, and environmental engineering will be required to plan, design, and manage this promising technology.

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