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# *Natural Wastewater Treatment Systems*

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The term wastewater treatment "plant" is taking on an entirely new meaning. Many regions of the U.S. are utilizing aquatic plants and animals as viable alternatives to conventional wastewater treatment systems. These "natural systems" include the use of floating aquatic plants, and natural and manmade wetlands.

Natural systems offer potential advantages: they are relatively inexpensive to build and operate and they may be utilized to enhance or restore wildlife habitats. Proponents say these systems represent a remarkably efficient method to treat domestic and industrial wastewaters. The treatment efficiency of various natural systems is shown in Table 1.

Many areas are looking into distinctly different natural systems. The City of San Diego, California, is using water hyacinths to treat its wastewater, and is studying whether the water can be treated to drinkable quality. EPCOT center at Walt Disney World, Florida, is investigating wastewater treatment systems using water hyacinths and other plants. The National Aeronautics and Space Administration (NASA) lab in Mississippi is studying water hyacinth and artificial wetland systems that treat domestic and industrial wastewaters. Their research may lead to systems that recycle water on long-term voyages to outer space. The Tennessee Valley Authority (TVA) is utilizing cattails to treat water polluted by mining, and is using artificial wetlands to treat domestic wastewater in demonstration projects in rural areas of Kentucky.

Texas cities and industries are also using natural systems to treat wastewater. Cities in the Rio Grande Valley have used water hyacinths to treat wastewater since the 1 970's. In the future, natural systems may be useful in treating drinking water from the Rio Grande. The City of Austin operates a large greenhouse filled with water hyacinths for advanced wastewater treatment. The Lower Colorado River Authority (LCRA) has designed a pilot project at Johnson City that will use
artifical wetlands and submerged flow systems. The Dow Chemical Company's

manufacturing plant in Freeport has used aquaculture systems to treat industrial wastewaters.

Texas universities are involved in natural systems research. Calvin Woods and Carlos Victoria- Rueda, researchers with Texas ABM University's Civil Engineering Department, are part of an effort funded by the Texas Water Resources Institute to predict the treatment capacity of water hyacinth systems. They are also investigating contaminant removal mechanisms in water hyacinth systems. Ernest Gloyna, former Dean of the College of Engineering at the University of Texas, has studied the use of oxidation ponds for wastewater treatment, and is now investigating whether spraying hyacinth leaves with wastewater increases treatment efficiency. Much of the work is being conducted near Austin at the Environmental Research Center: a joint venture of the City of Austin, Texas A&M University, and the University of Texas.

Despite the promise of natural systems, questions remain. In many ways, the technology is still unproven. Many systems, even well-designed ones, have failed because of cold weather, overloading, and mosquito and odor problems. Even after the technology is improved, policy makers will have to be convinced that natural systems consistently provide reliable results.

## *Basic Principles*

A number of factors influence the ability of a natural system to remove pollutants from wastewaters including plant species, algal activity, bacteria, fungi, plankton, bottom soils, and environmental factors such as the acidity of water (pH), temperature, water depth, and dissolved oxygen.

Four of the most important classes of pollutants in domestic wastewaters are nitrogen compounds, biochemical oxygen demand (BOD), phosphorus, and total suspended solids (TSS). Nitrogen removal is one of the most important and most complicated processes (see Figure 1). Nitrogen enters the wastewater in various forms such as ammonia, organic nitrogen, nitrite and nitrate. In basic terms, bacteria in aerobic conditions (with oxygen) such as plant roots or open wastewaters convert nitrogen to nitrate. The nitrate is usable by plants as a food source. Other bacteria living in anaerobic conditions (without oxygen) such as sediments convert nitrate into nitrous oxide and nitrogen gas which are lost to the atmosphere. BOD and TSS are removed through two processes: 1 ) Heavier solids physically settle and decompose; and 2) Lighter solids and soluble materials are metabolized by microorganisms. Natural systems remove phosphorus through absorption onto soil particles. Emergent plants may also be able to extract phosphorus from wastewaters. Harvesting plants or flushing but systems between growing seasons may be needed for additional phosphorus removal (Sbey and others, 1978).

The cooperative growth of plants, bacteria, fungi, and other microorganisms play a key role in natural wastewater treatment. Once microorganisms are established on plant roots they form a symbiotic relationship with the plants, degrading and removing organic chemicals from wastewater surrounding the root systems. The microorganisms degrade the organics, producing metabolites which they and the plants utilize along with nitrogen, phosphorus and other minerals as a food source. Zooplankton (small aquatic animals), bacteria, fungi, protozoa, leeches, earthworms, snails, asian clams, and insect larvae feed upon algae and other debris that cover the roots, enhancing treatment. By using each other's waste products as a food source, organics are rapidly removed.

Plant roots also transport oxygen into wastewaters and trap pollutants when electrical charges from plant root hairs react with opposite charges on suspended solids. Heavy metals and toxins can also be concentrated in the roots, or translocatedt o other plant parts. There are currently conflicting opinions over which factor - plant growth, sedimentation or microbial activity - is most responsible for nutrient removal.

Many plant-based systems are most effective when the plants are actively growing. During dormant periods, treatment efficiencies generally decline and additional storage or other plans species may be needed. For example, water hyacinth could be utilized during warm weather, while other cold-tolerant plants such as duckweed or pennywort could be introduced during the winter months. Florida research suggests that misting the plants during cold weather may reduce freeze damage (DeBusk and Reddy, 1986).

In animal-based systems, the whole food web contributes to pollutant removal. Larger animals provide a mechanism for complete removal of some pollutants. Smaller animals such as invertebrates and free floating animals feed on algae and bacteria.

## *Floating Aquatic Plants*

Much of the attention in natural wastewater treatment systems has focused on floating aquatic plants. Water hyacinths are especially attractive for wastewater treatment. The plants grow rapidly (2 plants multiplied to produce 1,200 in just 4 months in Louisiana) and as they grow they take up nutrients. Properly designed and operated water hyacinth systems remove 60- 95% of the BOD from wastewater.

Water hyacinths produce a unique ecosystem which improves wastewater treatment efficiency. Hyacinths usually cover an entire basin, lowering water temperatures, reducing wind action and limiting algal growth. Some hyacinth systems suffer from mosquito problems. Gambusia dish that eat mosquito larvae) can be introduced as a biocontrol. When using Gambusia, aerated zones should be provided where the fish will receive sufficient oxygen. Toxins should also be monitored to avoid fish kills. Another potential problem is that water hyacinths consume a lot of water: as much as had the wastewater entering a system can be lost to evaporation and transpiration. This may be a concern for cities required to provide return flow for downstream users.

Much of the research involving water hyacinth wastewater treatment systems has been performed at NASA's National Science Technology Laboratory (NSTL) at Bay St. Louis, Mississippi. NSTL scientists (Wolverton, 1987) developed the first operational water hyacinth system in the U.S. for treating industrial wastewater (1975) and domestic sewage (1976). The systems are effective and consistently meet BOD and TSS levels of

30 milligrams per liter (mg/l). NASA research also indicates that hyacinths and pennywort remove significant amounts of heavy metals and toxic chemicals. Toxins were metabolized by microorganisms on plant roots, and heavy metals were concentrated in plant tissues.

In San Diego, California, water hyacinths have been used since 1984 in a 300,000 gallon per day (GPD) system that receives primary treated sewage. The system is being expanded to treat 1 million gallons per day (MGD). Results (Tchobanoglous, 1987) suggest that extensive in- pond aeration increases treatment efficiency, particularly if high levels of sulfates are in the wastewater,
and that recycling wastewater throughout the system increases oxygen levels. BOD and TSS levels consistently average 10 mg/1, and the system has been able to withstand nutrient concentrations 300% above monthly averages. San Diego is now investigating H water from the system can be made drinkable through reverse osmosis and ultraviolet light disinfection.

Natural systems research is also underway at the Walt Disney World Complex in Florida. A 1986 investigation revealed that a pennywort-water hyacinth system reduced BOD concentrations in secondary effluent by 91%. Their research suggests that pennywort was effective at removing copper, lead, and organic chemicals from domestic wastewater (DeBuskand Reddy, 1987).

A water hyacinth system designed specifically for use in arid and semiarid climates has been developed by researchers at the University of Arizona (Foster and Warshall, 1988). Their work involves construction of a pilot scale project that will focus on the effect of summer heat stress, winter cold stress and taxies on system performance.

Water hyacinth systems may also be more economical than conventional wastewater treatment plants. One study reported that a hyacinth system would cost only half as much to construct and only two-thirds as much to operate as an activated sludge plant (Tchobanoglous and others, 1979). In small systems, the savings may be even greater. Hyacinth systems can be made even more profitable K products such as compost, methane gas, cattle feed, paper, or protein extract can be developed and marketed. Hyacinths used for livestock feed or protein should be grown in domestic wastewaters so that they would be free of heavy metals or toxins.

Other plants including duckweed may also be useful in natural systems. Duckweed has a much wider geographic range than water hyacinth because it survives in colder climates. A continuous mat of duckweed prevents algal growth and creates anaerobic conditions, preventing mosquito production. Using duckweed in combination with pennywort is another method that may be successful where cold weather may be a problem. However, duckweed and pennywort are reported to be less than half as effective as water hyacinth at supplying oxygen to wastewaters. Researchers are also looking at other floating aquatic plants that are more tolerant to cold weather and saline water.

The combination of aquatic plants and aquacultural systems is also being investigated.

These systems employ bacteria, algae, microscopic aquatic animals, higher plants, fish and crustaceans to treat wastewaters. In the 1970's, the Texas Department of Health (TDH) researched the use of Daphnia (a small crustacean) to treat stabilization pond effluent. Daphnia trap suspended solids with fine hairs on their legs, and their constant swimming activity increases aeration. TDH also investigated a wastewater treatment system using stabilization ponds stocked with Daphnia, snails, insects, shrimp and fish in sequence (Dinges, 1976a).

A greenhouse-enclosed wastewater treatment system that combines plants and aquatic animals is now in operation in Vermont. A wastewater stream flows through four distinct ecosystems where a wide range of plants including dogwoods, willows, artichokes and eucalyptus, are rafted on the water surface of each segment. The final stage is a rock filter planted with reeds, bulrush, and cattails. The trees consume nutrients as they grow and their root systems provide habitat for grazing snails that consume algae and other contaminants. The snails are then fed to trout and bass nursery stock. The 3,000 GPD system reduced BOD by 97%, TSS levels by 96%, and ammonia by 99% (Todd, 1988).

## *Natural and Artificial Wetlands*

Plants that may be utilized in natural and man-made wetlands include floating aquatic plants, cattails, reeds, and bulrush. In most cases, natural wetlands can only receive secondary treated effluent. Discharge of raw or primary treated sewage may violate the federal Clean Water Act.

There are a few instances where natural wetlands have been used for wastewater treatment. The City of Arcata, California, discharges treated effluent into 35-acres of wetlands as part of its wastewater treatment system. Five acres of wetlands are planted with bulrush and are used specifically for wastewater treatment. This nutrient rich effluent then flows to 30 acres of wetlands designed to enhance wildlife habitat that are planted with cattails, grasses and other marsh plants. The treated wastewater flows to nearby coastal oyster beds and it is also being mixed with seawater to rear salmon to smolt size. The system began receiving treated effluent in 1986, and BOD levels have been reduced by 83% and TSS concentrations have been reduced by 75% (Allen and others, 1987).

A large full-scale forested wetland system utilized for wastewater discharge is located near Orlando, Florida, where swamp forests have been used for effluent disposal since 1977 (Knight and others, 1987). Chlorinated secondary treated effluent flows into the 86-acre wetland system where it is detained between 4-13 days. BOD, TSS, and total nitrogen concentrations have consistently averaged less than 2 mg/l.

Natural wetlands can be effective in removing nitrogen from wastewaters, lessening the risk of algal blooms in rivers and lakes. Florida data indicate that nitrogen removal rates are 58-82% for marsh and shrub wetlands and 6988% for forested swamps (CH2M Hill, 1986). Removal rates for other Florida wetlands are 93% for N. 82% for BOD, 80% for TSS, and 31 % for P.

Regular discharges of wastewaters into a wetland may alter existing vegetation, because some species such as cypress, gum, maple and ash require extended dry periods to germinate and reach maturity. Mature trees do not appear to be harmed unless discharge rates are excessive. Wastewater flows may enhance habitat for birds, mammals and reptiles, and increased numbers of herons, ospreys, egrets, raccoons, turtles, and water snakes have been reported at Florida sites.

Artificial wetlands wastewater treatment systems originated in West Germany in the 1970's at the Max Planck Institute, where the root zone method was developed (Tourbier and Pierson, 1976). Typically, artificial wetlands consist of emergent plants such as reeds, iris and cattails which are planted in a bed of soil, gravel or some other medium. Wastewater can be introduced to the system at the root level or above ground. The pollutant removal mechanism in artificial wetlands is basically the same as it is in other systems. Contaminants are removed in the root zone and through plant growth.

In the U.S., NASA has been instrumental in designing systems utilizing rooted aquatic plants in microbial rock filter beds. Nitrogen, BOD and TSS can be removed using relatively short detention times, and the systems have been used to remove toxic chemicals from Mississippi River water. NASA results suggest that these systems may be better than floating aquatic plant systems because they are: 1) Better suited to reducing hazardous and toxic chemicals; 2) Less vulnerable to shock loading; 3) Not likely to produce odor problems; and 4) Able to perform better in cold climates and/or saline waters. NASA experiments utilizing torpedo grass and bulrush removed upto 96% of toxic chemicals within 24 hours. This type of system could be used to reduce salts as an inexpensive alternative to reverse osmosis. Water hyacinth/rooted plant systems could be utilized to clean up sites contaminated with radioactive wastes (Wolverton, 1988a).

Artificial wetlands systems are now in operation in Pennsylvania, Louisiana, Mississippi and other areas. In Haughton, Louisiana, raw sewage passes through a lagoon and an artificial marsh stocked with pennywort, bulrush and lilies. The system is designed to treat 350,000 GPD and has been operating for a year. BOD values have been reduced from 45 to 10 mg/1, and TSS concentrations have been cut from 115 to 7 mg/l (Wolverton, 1988b).

TVA researchers have investigated the effectiveness of wetland plants in removing acidity, sulfate, iron, manganese and other pollutants from acid mine seeps (Brodie and others, 1987). Cattails, moss and bulrush were planted in areas contaminated by coal slurry disposal ponds. The plants grew vigorously, increasing dissolved oxygen and lowering iron and TSS levels.

## *Texas Research Results*

Some of the early water hyacinth research in Texas was carried out by the TDH (Dinges, 1976b). Results indicated that the hyacinths removed nitrogen, BOD, TSS, fecal coliform bacteria, and algae from the wastewater, and accumulated heavy metals and minerals in plant tissues.

The effectiveness of water hyacinths in reducing concentrations of organic wastes and TSS in industrial effluent was evaluated at the Exxon Baytown Complex in 1976. Results indicated that water hyacinth reduced TSS levels by 78% in an advanced treatment system (Chambers, 1978).

The City of San Marcos investigated the use of water hyacinths in a solar-powered wastewater treatment system in 1980-81 (Venhuizen, 1981). The project focused on the use of wind power to provide supplemental aeration and the use of greenhouses to keep the plants growing year-round. The report suggested that solar-powered water hyacinth systems hold promise for providing low-energy wastewater treatment.

Texas A&M University research projects are now investigating pollutant removal mechanisms in hyacinth based wastewater treatment systems. Research is being conducted by Calvin Woods and Carlos Victoria-Rueda. The research consists of two phases. First, uptake of organics and the release of particulates by sloughing were assessed under laboratory conditions where light, temperature, plant density and flow rates were controlled. An outdoor pilot plant is now being set up under "real world" conditions to confirm observations made during the first phase (Victoria-Rueda, 1988). Victoria-Rueda also developed a model (HYAMOD) which simulates BOD removal in water hyacinth treatment systems (Victoria-Rueda, 1987).

## *Texas Experiences*

The Texas Water Commission regulates the use of natural wastewater treatment systems, and permits to use these systems are reviewed on a case-by-case basis. Water hyacinth systems are approved for treating wastewaters beyond secondary treatment levels, although only systems in Hidalgo, Cameron and Willacy counties are allowed to operate without greenhouses. Permits must also be obtained from the Texas Parks and Wildlife Department before hyacinths can be used.

Small towns in the Rio Grande Valley including Donna, Edcouch, Alamo and others have been using water hyacinth systems since the mid-1970's, but the only systems still in operation in the region are at Rio Hondo and San Bongo. Many of the systems experienced operating problems including water that was too saline and killed the hyacinths; buildup of sediments that raised BOD levels and overloaded the systems; freezing temperatures; and predation by insects and animals.

The City of Austin's Hornsby Bend Hyacinth Facility consists of three water hyacinth ponds enclosed in a 5-acre greenhouse. One-tenth of each pond is kept free of hyacinths accelerating algal growth and providing supplemental oxygen. These open areas also provide excellent habitat for mosquito fish, crustaceans, and frogs which control pests and help clean the effluent. The ponds are designed to treat 0.8 MGD of wastewater from 30 mg/1 BOD and 90 mg/1 TSS to 10 mg/1 BOD and 15 mg/1 TSS. The system has been overloaded in the past. Still, TSS levels were reduced by 80% and BOD concentrations were cut in half in 1986-87 (Doersam, 1987).

The San Bongo water hyacinth facility began operating earlier this year, and is designed to treat 2.2 MGD. Hyacinths are used to treat wastewater that has already flowed through facultative and oxidation ponds. The facultative ponds use bacteria and other microorganisms to break down organic solids. Algae and Daphnia are utilized in the oxidation ponds. Grass shrimp, minnows, monies and mosquito fish in the hyacinth basins feed on the organisms that were grown in the first two ponds. The plant is permitted to meet discharge levels of 30 mg/l for BOD and TSS.

The LCRA recently completed the design phase of a demonstration project at Johnson CRy which will evaluate the effectiveness of free water surface wetlands (long and shallow basins where wastewater flows over emergent aquatic plants) and submerged flow systems (wastewater flows beneath a permeable media to the root zone of emergent plants). The system is designed to meet treatment levels of 5 mg/1 BOD, 5 mg/1 TSS, 2 mg/1 ammonia and 1 mg/l phosphorus.

## *Summary*

Natural systems show considerable promise in providing cost-effective treatment of domestic and industrial wastewaters. Some of the systems that may benefit Texas include floating aquatic plants, artificial wetlands, and systems combining aquatic plants and animals.

Although these systems offer a potential alternative to conventional wastewater treatment, more information is needed. Natural systems must be well-designed to prevent problems with the release of pathogens, heavy metals, and other pollutants into the environment. University and private sector research into proper design criteria, loading rates, cold- tolerant plant species, and management techniques to prevent pest problems are needed to develop more reliable systems. If properly designed and operated, these systems offer an opportunity to meet many of Texas' wastewater treatment needs.

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