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Used primarily to treat wastewater, constructed wetlands also can be an attractive natural setting where wildlife builds habitat and humans visit. Above is the Hayfield Site at the Tres Rios demonstration constructed wetlands. (Photo: Bing Brown, Phoenix Water Services)

Constructed Wetlands: Using Human Ingenuity, Natural Processes to Treat Water, Build Habitat

by Joe Gelt

Consider the phrase "constructed wetlands." Although not a contradiction in terms, the two words make up an unlikely combination. Construction implies a project fabricated and built by humans. What then has construction to do with wetlands, natural areas formed by the complex workings of geology, biology and hydrology?

Even the word "wetland" by itself conveys mixed meanings. Wetland implies an area that is neither wholly land nor water, with characteristics of both terrestrial and aquatic systems. When speaking of wetlands, the expression "Neither fish nor fowl" might be quoted – or, turning the phrase about, a variation might aptly be coined, "Fish, fowl and mammal," to describe the wide variety of wildlife attracted to the combined terrestrial-aquatic wetland environment.

Joining technology with natural processes, constructed wetlands do indeed have wide and varied implications. An increasingly important water topic, constructed wetlands are attracting the interest and attention of many, from wastewater treatment personnel to environmentalists, in Arizona and throughout the world.

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What is a Constructed Wetland?

In brief, a constructed wetland is a water treatment facility. Duplicating the processes occurring in natural wetlands, constructed wetlands are complex, integrated systems in which water, plants, animals, microorganisms and the environment – sun, soil, air – interact to improve water quality.

To the extent that what is human-made is artificial – while what is formed by nature is said to be natural – constructed wetlands are artificial wetlands. Whereas geology, hydrology and biology create natural wetlands, constructed wetlands are the result of human skill and technology. Humans design, build and operate constructed wetlands to treat wastewater.

Yet to refer to constructed wetlands as purely artificial, human-made or engineered is not entirely accurate and slights their most significant feature. By utilizing, and even attempting to optimize the physical, chemical and biological processes of the natural wetland ecosystem, constructed wetlands also are, to various extents, natural environments.

If properly built, maintained and operated, constructed wetlands can effectively remove many pollutants associated with municipal and industrial wastewater and stormwater. Such systems are especially efficient at removing contaminants such as BOD, suspended solids, nitrogen, phosphorus, hydrocarbons, and even metals. They are used to treat municipal effluent, industrial and commercial wastewater, agricultural runoff, stormwater runoff, animal wastes, acid mine drainage and landfill leachates.

Although a primary purpose of constructed wetlands is to treat various kinds of wastewater, the facilities usually serve other purposes as well. Research might be conducted, to study and evaluate the workings of the wetland process. A wetland also can serve as a wildlife site, to attract various animals and provide habitat. Also a wetland can be a public attraction welcoming visitors to explore its environmental and educational possibilities.

Constructed wetlands are increasingly being used in Arizona to treat wastewater. In 1990, Arizona had only four constructed wetlands treating municipal wastewater. Today 26 municipal and on-site constructed wetlands are operating in the state, with at least 24 others either awaiting approval or under construction.

Constructed wetlands in Arizona vary greatly in size and function, serving municipalities, businesses and individual homes. The Kingman constructed wetland facility has a volume of three million gallons per day. The constructed wetland at Jacob Lake Inn treats effluent from campgrounds, rental cabins and laundry and its volume is about 2,000 gallons per day. The constructed wetland at the Yuma-Mesa Irrigation District Vehicle Maintenance Yard treats vehicle "wash rack" runoff and has a volume of less than 200 gallons per day.

Advantages, Benefits of Constructed Wetlands

Constructed wetlands provide various advantages. This widens their appeal among different interests, from engineers and those involved with the workings of wastewater treatment facilities, to environmentalist and people concerned with recreation. Unlike some water issues, in which the advantages to one group are disadvantages to another, the effective operation of constructed wetlands can provide broad benefits to a range of interests.

The Tres Rios Constructed Wetlands Demonstration Project outside of Phoenix demonstrates some of the advantages of constructed wetlands. The facility is testing the effectiveness of wetlands to treat effluent from the Phoenix 91st Avenue Wastewater Treatment Plant. Begun in 1995, Tres Rios is the first step in developing a more expansive constructed wetlands facility.

The Phoenix Water Services Department operates the Tres Rios project, on behalf of the multi-city Sub-Regional Operating Group. SCROG includes the cites of Glendale, Mesa, Phoenix, Scottsdale and Tempe. Other project participants include the U.S. Bureau of Reclamation, Environmental Protection Agency and the engineering firms of CH2M Hill and Greeley and Hansen.

Phoenix officials developed the Tres Rios project as part of a strategy for meeting expected tougher federal water quality standards for sewage treatment facilities. Anticipating that an upgrade of the 91st Avenue plant would be costly, officials sought a less expensive option.

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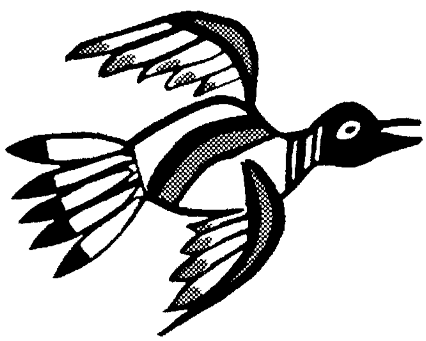
Not relying on concrete and steel, constructed wetlands usually can be built at less expense than other treatment options. The Tres Rios pilot project cost $3.5 million to build. Compared to the $625 million officials estimated would be needed to upgrade the 91st Avenue plant, the expected cost of expanding the Tres Rios constructed wetlands pilot project into a full-scale water treatment facility is $80 million.

Constructed wetlands treatment techniques and methodologies promise further advantages. Research is demonstrating the effectiveness of natural processes for treating wastewater. Further, with low-tech methods in place, no new or complex technological tools would be needed. Plants and microorganisms are the active agents in the process.



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Another advantage of constructed wetlands is that operation and maintenance costs are likely to be less than a conventional treatment plant. Less energy and supplies are needed, and constructed wetland facilities can get by with periodic on-site labor, rather than continuous, full-time attention. At Tres Rios two full-time employees operate and maintain the facility.

A recent convert to constructed wetlands, the town of Jerome chose this process over a mechanical treatment plant to treat its wastewater. Maintenance of the mechanical treatment plant was to cost about $1,000 per month while the cost to maintain the wetland is expected to be "little or nothing." Construction is expected to begin this summer.

Other kinds of benefits also accrue. By duplicating the natural processes that occur in wetland ecosystems, Tres Rios is much more than just a highly efficient wastewater treatment facility. Tres Rios has become to some extent the real thing, a functioning wetland, a site with available water and emergent vegetation attractive to varied wildlife. Environmental attractions are an important feature of many constructed wetlands.

Visitors at Tres Rios come to see its slowly moving water meandering among clumps of vegetation and to view various wildlife. Forty-five different bird species have been sighted in the area as well as reptiles, fish and other animals, including a beaver colony. Often deemed "ancillary benefits," to many people such environmental features are the main attraction of constructed wetlands.

Tres Rios and other constructed wetlands are increasing wetland areas within the state. In Arizona, and in other regions of the United States, natural wetlands have acquired the status of an endangered specie. Once generally viewed as land of little value and less use, wetlands were considered marginal and expendable. As a result, few of Arizona's original wetlands remain intact.

Natural Wetlands

To comprehend the constructed wetlands treatment process, the workings of natural wetlands must be understood. Natural wetlands are variously called swamps, marshes, bogs, fens, wet meadows, sloughs, or, in the U.S. Southwest, cienegas and tinajas. The wetlands these terms define are not necessarily all the same. Plant types, water and geographic conditions vary, creating different kinds of wetlands.

Wetlands are transitional areas between water and land. The 1977 Clean Water Act Amendments provide a broad definition of wetlands: "The term 'wetlands' means those areas that are inundated or saturated by surface or groundwater at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions."

Wetlands are natural receptacles. Occurring in low lying areas, wetlands receive runoff water and overflow from rivers and streams. In response, various wetland biological mechanisms or processes evolved over geologic time to treat inflows. These mechanisms trap sediments and break down a wide range of pollutants into elemental compounds.

Wetlands have a natural, innate ability to treat wastewater. Water moves slowly through wetlands, as shallow flows, saturated substrates or both. Slow flows and shallow waters cause sediments to settle. The slow flows also act to prolong contact times between the water and surfaces within the wetland.

The organic and inorganic materials within a wetland form a complex mass. This mass along with the occurrence of gas/water interchanges promotes a varied community of microorganisms, to break down or transform a wide variety of substances.

Dense growths of vascular plants adapted to saturated conditions often thrive in wetlands and contribute to its treatment capacity. Along with slowing the flow of water, the vegetation creates microenvironments and provides the microbial community attachment sites. Further, plants die back in the fall and accumulate as litter. This creates additional material and exchange sites as well as providing a source of carbon, nitrogen and phosphorous to fuel microbial processes.

Workings of Constructed Wetlands

The above very briefly describes the natural process adapted for use in constructed wetlands. Constructed wetland projects may differ in operation and treatment goals, but all rely on this natural process. Describing wastewater treatment at Tres Rios – although it may differ from what is occurring at other constructed wetlands – will help explain the adaption of the natural process for use in human-made wetlands.

The Tres Rios pilot project is both an operating facility and also a testing laboratory. Wastewater is being treated, and various configurations of the natural process are being tested, in an effort to find the most appropriate design, construction and operations criteria for later use in a full-scale wetlands.

Constructed wetlands are part of a treatment train, one stage in the treatment process. At the Tres Rios wetlands, wastewater is first treated at the 91st Avenue plant to a secondary advanced level. This wastewater has fewer nutrients and is of higher quality than secondary treated wastewater. Tres Rios must receive high quality wastewater because of its wildlife habitat. Constructed wetlands are capable of treating wastewater of much lower quality, including primary treated wastewater. Primary treated wastewater treatment generally is limited to physical separation. Filtration removes floating materials, and solids settle out. Access to wetlands with primary treated wastewater would likely be restricted for humans and most animals.

The Tres Rios wetlands consists of three sites covering 14 acres. Located within a riparian/upland area on the north bank of the Salt River, the six-acre Hayfield Site is made up of two separate cells. Operated either in series or parallel, the cells are arranged to determine the effectiveness of constructed wetlands for wastewater polishing and the best cell configuration for optimum water quality.

Located within the Salt River floodway, the 4.5-acre Cobble Site consists of two parallel basins. One is lined with topsoil to facilitate vegetation establishment and to reduce water infiltration. The other is unlined, duplicating conditions when locating a full-sized wetland in the sand and cobble of the river bottom. The feasibility of creating wetlands in such soil conditions and the ability of the wetlands to rebound after flooding is being tested at this site.

Tres Rios uses a three-phase wetland system, with wastewater moving from marsh to deep pool then back to marsh, through both emergent and open-water areas. Wastewater first flows into the emergent area of a shallow marsh for initial treatment. Ranging in depth from 0.5 to 1.5 feet, the shallow areas include cattails, reeds and bulrushes. Providing the best waterfowl habitat, bulrushes are uniformly planted in the emergent marsh areas.

(Biologists speculate that the abundance of vegetation at Tres Rios may attract the clapper rail, an endangered specie. This could pose an interesting regulatory situation. How would the presence of an endangered species in a constructed wetland affect its management?)

Water then collects in the deeper, open-water pool, from 3 to 4.5 feet deep. By moving from shallow water to deep water before flowing back to shallow water, wastewater becomes remixed. This ensures the water will contact more surfaces, whether on the bottom of the pool or the submerged portion of the vegetation. More treatment thus occurs. Further, the deep pools slow down the flow of water before entering the next flow path, and this ensures more treatment time.

The deep pools are an important habitat area for wildfowl and include nesting islands. At one time submerged aquatic plants grew in the Tres Rios deep pools, but they were eaten by a species of tilapia, a non-native fish, that got into the pools. Fish-eating birds such as blue herrings, night herrings and egrets stalk the edges of the deep pools seeking fish.

From the deep pools the wastewater then enters the second marsh. Here bulrushes filter and treat waste products added by waterfowl and algal production in the deep pool. Treated water then flows into the normally dry Salt River bed.

What happens to the wastewater after wetland treatment is an important issue. Consideration of its eventual use helps determine the quality of wastewater released to the wetlands and the type of wetland treatment process used.

Nature provides the model not just for the treatment process, but also for the physical design of Tres Rios. The shape of the cells are designed to duplicate natural wetlands. Avoiding straight edges, the cells have irregular borders providing micro-habitats for attracting aquatic and semi-aquative organisms.

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Covering three acres, the third Tres Rios site consists of 12 small research cells. Located within an abandoned sludge-drying basin, these cells are closely monitored to test various aspects of the treatment process. For example, one of the primary research goals is to determine what effect increasing the number of deep zones has on water quality.

Following are case studies of various Arizona constructed wetlands. They include not only descriptions of various types of operations, but also identify diverse issues associated with constructed wetlands.

Pintail Lake/Redhead Marsh

The Show Low constructed wetland in northeastern Arizona was the first in the state and one of the first in the nation. As a result, the facility attracts national attention and is often mentioned in constructed wetland literature.

Along with its historical importance, the Show Low facility generally offers what many people expect of wetlands. Located in an attractive natural setting, the wetland has an abundance of wildlife, with a flow of water slowly meandering through clumps of vegetation. Vegetated islands host nesting waterfowl, and the wetlands attract varied wildlife. Creating wildlife habitat is central to the design and operation of this wetland.

The Show Low facility is actually a complex made up of several wetlands. Pintail Lake, the first to be built, began receiving municipal wastewater in 1979. The site is located on National Forest Service Land. Two government agencies, the USFS and Arizona Game and Fish, teamed up with the city to construct the wetlands, a partnership that continues today. Other groups have since joined, including the Audubon Society.

To create Pintail Lake, effluent was pumped into a playa or natural depression. Water control structures and two dikes were built within the depression, and the USFS constructed 14 nesting islands to enhance waterfowl reproduction. The islands were to protect nesting wildfowl from predators such as skunks and coyotes. Seeded with several plant species, the islands then were covered with straw to retain moisture and protect the islands from erosion.

Initially the 47-acre lake received 200,000 gallons of wastewater per day, an amount that has since increased to 500,000 gallons of municipal secondary effluent. In 1986, the Show Low complex expanded to include other wetlands, including Redhead Marsh and Telephone Lake, to form a complex made up of several lakes and marshes. The complex now consists of nine cells covering about 200 acres that can handle 1.42 million gallons of wastewater daily to serve a population of 13,500. The treated water is not discharged from the wetlands but remains to evaporate and create habitat.

The treatment facility supplying effluent to the wetlands uses aeration lagoons, stabilization ponds and a chlorination chamber. The effluent then enters the wetlands treatment system which includes polishing ponds, lakes, open channels, riparian areas and marshes. Management of the wetlands involves controlling water quantity, quality and delivery, with water levels also carefully regulated. Water can be diverted to allow some ponds to dry up to manage vegetation and for maintenance.

Establishing a vigorous vegetative cover was essential to treat wastewater and attract wildlife. Cattail, water grass, spike rush and various sedges established naturally in the wetlands. Successful plantings include hardstem, softstem and alkali bulrushes and sego pondweed. Fencing keeps domestic livestock from grazing in the area.

Operators of the wetlands measure the success of the facility in part by the number of wildlife attracted to the area. A 16-week survey conducted in 1991 identified 125 bird species using the wetlands. Ten birds classified as either endangered, threatened or sensitive were found at the wetlands. The area also attracts Rocky Mountain elk, mule deer, pronghorn, black bear, coyote, raccoon and various kinds of amphibians.

Pintail Lake is open to the public and attracts human visitors, from in-state, out-of-state and even foreign countries. Its public use plan includes a paved trail for handicapped access and a viewing blind that accommodates 50 students. Local students use the facility as an outdoor classroom to learn about recycling, wetland ecology and wildlife.

Environmental Features Questioned

In many minds constructed wetlands and environmental or wildlife attractions go together. This is because the constructed wetland projects that generally catch the attention of the media are those with interesting environmental features. Not all constructed wetlands, however, have environmental amenities. And others that do are being found wanting by some biologists who question how carefully the environmental features are worked into the wetland project.

The City of Kingman has a constructed wetland designed specifically for wastewater treatment, without environmental attractions. That the facility was designed primarily for water treatment is apparent from its design. The wetlands consist of two trains, each with three cells. Each cell is about a half mile long and 150 feet wide. A train has 25 acres of wetland surface area and can treat about one million gallons per day. Kingman's constructed wetland is the largest municipal constructed wetland in Arizona.

Kingman city officials decided against a wetland with environmental attractions because of a concern with liability. Such features would attract public attention, and officials did not want the city to be responsible for visitors. Further, city officials feared that a constructed wetland with wildlife habitat likely would attract hunters. With minimal staffing at the facility, no one would be available to police the area.

(Officials at the 91st Avenue plant in Phoenix have had problems with hunters shooting into the wetlands. Also an explosive device was thrown into one of the pools killing a number of fish.)

The Kingman constructed wetlands, however, still attracts wildlife. Black birds, rails, sparrows and wrens use the facility, with migratory birds and shore birds also visiting. The fence surrounding the facility does not keep out deer and elk. The scarcity of water in the desert ensures that a body of water, even without any built-in environmental appeal, still will draw varied wildlife.

Meanwhile some biologists are concerned that constructed wetlands with environmental enhancements are not being planned properly and that their wildlife appeal is sometimes overstated. Marty Jakle, a biologist and bird watcher interested in riparian areas, raised such issues in a letter to the Arizona Department of Environmental Quality.

He noted that most pictures of constructed wetlands show very homogeneous dense stands of emergent macrophytes, usually cattails or bulrush. These are habitats with little plant species or structural diversity. As a result, he questions what types of environmental enhancements are occurring and whether constructed wetlands are, in fact, providing high quality habitat.

He notes that constructed wetlands often attract common species such as the American coot, song sparrow, and redwinged blackbird and questions whether creating breeding habitat for such species should be a priority. Instead, he argues constructed wetlands should be designed to attract wildlife in need of habitat improvement.

He believes the environmental cause would be best served if habitat types were identified early in the wetland planning process. Various habitat types then could be considered; e.g., habitats for neotropical migrants (warblers, tanagers, flycatchers, etc.), for sensitive species (clapper and black rails, snowy egrets, leopard frogs, ect.) or for common species for educational purposes (great blue heron, American coot, black-necked stilt, etc.).

Other biologists say the ratio of open water to vegetation within constructed wetlands needs to be carefully considered. Ideally the ratio should be about 50/50 to create the best wildlife habitat. Not all constructed wetlands maintain this ratio. Further, some biologists say that designers of constructed wetlands should vegetate the adjacent riparian area which is different than wetlands. Otherwise the wetlands are out of context. Cottonwood and willows should be planted to created a riparian area adjacent to the wetland.

Sweetwater Wetlands, a Community Project

Since it can offer environmental, recreational and educational benefits, a constructed wetlands project can attract public interest and participation, much more so than, for example, a conventional sewage treatment plant. In fact, a carefully and creatively managed constructed wetlands project can become a community project, with people willingly contributing to its planning, design and even its construction and operation. Tucson Water's Sweetwater Wetlands is such a community outreach project.

In what might seem an inauspicious beginning, Tucson's Sweetwater Wetlands project originated in response to a suit filed by the Arizona Department of Environmental Quality. The suit alleged the city was in violation of state drinking water monitoring and reporting requirements. Tucson subsequently negotiated a settlement that committed the city to, among other things, design and construct an experimental wetland/recharge facility, with associated wildlife habitat and educational amenities.

Tucson Water officials requested that Mayor and Council approve a Public Notification and Participation Plan for the City's Wetlands/Recharge Project. Approved in October 1994, the plan called for establishing an ad hoc Citizens' Wetlands/Recharge Advisory Committee, with members appointed by the Mayor and Council. Serving as a sounding board for community sentiment, the committee participated in the planning and designing of the project.

Project participation further broadened, with various federal, state and local agencies as well as nongovernmental organizations assisting the committee, the city staff and the consultant team in designing the facility. Among those joining the effort were the U.S. Fish and Wildlife Service, Arizona Game and Fish Department, City Parks and Recreation Department, University of Arizona, Arizona Native Plant Society, Arizona-Sonoran Desert Museum, Tucson Audubon Society, and Tucson Resources Center for Environmental Education.

Ten committee meetings and three informational open houses were held from December 1994 through early September 1995. The committee came up with various facility design recommendations. For example, the committee recommended that one of the two wetland ponds be without public access, thus preserving it exclusively for wildlife. Limited parking facilities was another recommendation to control the number of visitors.

To build bridges with local educational organizations, a Wetlands/Recharge Educational Outreach Program was established. Amphitheater School District's REACH Program and Pueblo High School's Advanced Media Productions class became directly involved. REACH students spent a semester learning about wetlands, and they recommended various educational components to include in the facility design. The students also designed the official logo for the project. They presented their recommendations to Mayor and Council during a May 1995 study session.

Pueblo High School Students produced three video documentaries depicting the public participation process and the activities of the REACH students. Their documentaries have been aired at local schools and shown to Mayor and Council. This elaborate and extensive exercise in public involvement has attracted national attention and is serving as a blueprint for public involvement efforts in other cities.

Central to this public activity and, in fact, the reason for it, is the wetlands itself, a facility to further treat wastewater for recharge and reuse. The Sweetwater Wetlands is to be a first stage expansion of the city's water reclamation facilities.

The city's reclaimed water treatment plant's filters are periodically cleaned by backwashing. The backwash water then is recycled through the county's treatment plant for reprocessing, at an annual cost of about $100,000. Instead of being reprocessed by the plant, the backwash water now is to be treated in the Sweetwater Wetlands.

The backwash water first will be conveyed to settling ponds to separate suspended solids, before entering the polishing basins or the wetland ponds. After physical separation occurs in the settling ponds, microbiological transformations take place in the wetland ponds. The backwash water will be treated to meet or exceed secondary standards. Sweetwater Wetlands will have 1.2 acres of settling basins, two wetland ponds totalling 17 acres with a volume of 300 acre-feet and six acres of recharge basins. About 300 acre-feet of backwash water will be treated annually for recharge.

Estimated total construction cost is about $1.7 million, with about $600,000 earmarked for public-use amenities. The facility design was finalized in late 1995. Construction is expected to be completed in early autumn 1997.

Other Wetland Benefits

Some type of water resource management innovation has occurred when Sweetwater, a constructed wetland wastewater treatment facility, can become a community or civic project, with citizens willingly contributing time and effort, from offering design suggestions to creating logos and planting trees. The project obviously is serving a broader purpose than just wastewater treatment.

Along with whatever public relations benefits it promotes, citizen involvement, very apparent at Sweetwater but encouraged in other such projects as well, is helping to change attitudes about the use of technology and about wastewater as a water resource. Such attitude changes may be another notable achievement of constructed wetlands.

Some environmentalists and other people at times have been wary of technology, especially when used to adapt natural processes to serve human needs. They fear its careless use can be destructive to the natural world. And admittedly human interference in the natural world has occasionally caused damage. For example, the dams that form lakes often harm and even destroy riparian ecosystems.

Unlike dams, however, constructed wetlands demonstrate that human projects can work in harmony with natural processes, to the advantage of both humans and the natural world. This experience can help define a suitable environmental role for technology. To some, technology may then seem less threatening.

Also, using wastewater to create wetlands helps redeem wastewater from its status as a befouled residue of civilized life or, in other words, water waste. It enables even wastewater to share, to some extent, the image of water as a basic and elementary resource, with the potential to support life, satisfy human needs, and even be a source of beauty. The role of water in our lives, especially our civilized lives, thus is better understood and appreciated.

Domestic Wetlands

Constructed wetlands range broadly in size, from the very large scale municipal systems to smaller systems for individual, single-family residences. Many homeowners likely find the idea of a constructed wetland appealing. To have one's very own personal wetland certainly is an attractive thought. Also, and more significantly, constructed wetlands, by providing water for outside use, help conserve water.

A constructed wetland, however, is an option for only very few homeowners. Homeowners living in urban areas usually are required to connect to a sewer system, and people in outlying areas generally use septic tanks and leach fields. Only if conditions are unsuitable for a septic tank and leachfield can a homeowner adopt an alternative means of on-site disposal.

For example, a septic system is not suitable if the building site has ten feet or less of soil to bedrock. Nor is it suitable if the site has tight or impacted soil that percolates at less than one inch per hour in a water percolation test or has a high water table. Since such conditions preclude the use of a conventional soil absorption system, homeowners in such situations could consider wastewater treatment alternatives.

A constructed wetland is such an alternative, although it is often referred to as an "non-conventional" option. Its dubious status is due to its relatively recent use in Arizona, despite their long-time use in other states. As a result, some officials believe that constructed wetlands for domestic use have not been adequately tested in this state.

Most constructed wetlands to treat domestic wastewater are subsurface systems. Wastewater then is not exposed on the surface of the yard or property, to raise odor, insect, public health or safety concerns.

In a constructed wetland system for domestic use, wastewater first flows to a septic tank which acts as a primary treatment system. Here solids are settled. From the septic tank, the effluent flows through a perforated inlet or distribution pipe buried in rock or gravel into vegetated submerged beds. Plants typical of subsurface flow wetlands are bulrushes and cattails; ornamentals such as canna lily, pickerelweed and arrowhead also are effective in treatment.

Subsurface wetland flow systems work on the principle that aquatic plants transfer oxygen from above-surface leaves to sub-surface roots. Aerobic bacteria attach to the roots, and anaerobic bacteria attach to the rocks. The effluent flowing through the wetland is treated by the action of the bacteria attached to the plant roots and rocks.

After treatment the water is released. Disposal options include reusing the treated water on turf. Another option is to install a drip system to irrigate the landscape in the yard. These options involve subsurface disposal systems with no human contact with the treated water. Other uses include evaporating the water in a pond or watering livestock.

Not all domestic constructed wetlands are subsurface systems. Some interesting projects are underway to treat domestic wastewater for use in designed and landscaped ponds. Several households, at least four or five, would pool wastewater for use in a common wetland. Some landscapers and designers are promoting this use of constructed wetlands to create pocket parks in cul-de-sacs and other places having a cluster of houses and a common area.

Not many Arizona homeowners have on-site wetlands to treat their wastewater. First of all, not many of them live in areas with conditions to justify installing a constructed wetland. Also strict regulations presently discourage householders from building wetlands. However, constructed wetlands for domestic use may increase in Arizona in the future. As the state continues to grow, construction is occurring in areas with unsuitable conditions for septic tanks and leachfields. People settling in such areas might decide to install wetlands.

Wetland Research at the Rovey Dairy

The University of Arizona, USDA's Natural Resources Conservation Service and the Rovey Dairy in Glendale are working together on a constructed wetland project to treat the dairy's wastewater. The project serves three purposes, to equip an operating dairy with an improved wastewater treatment system, to enable the dairy industry and the regulatory community to evaluate an innovative treatment option and to provide researchers an opportunity to study the system. An ADWR augmentation grant funds the project, with ADEQ providing funds for water quality work.

Because of its size and complex operations, Rovey Dairy is an appropriate facility to host the project. Dairy farms are becoming large operations, both in Arizona and nationally. With 1,750 cows, the Rovey Dairy can be considered "high average." (The average Arizona dairy herd size is about 1000 cows.) Research results gained here will be applicable to similar operations.

Between 50,000 and 60,000 gallons of dairy wastewater is expected to enter the system each day. Recycling this water could represent a significant savings to the dairy. Uses of the treated wastewater, however, will depend upon its quality when it leaves the wetlands.

The project, by studying what is occurring within and under the wetland ponds, will enable researchers to better understand the workings of the treatment process and the variables affecting it. University of Arizona researchers are involved in the project from the departments of Soil, Water and Environmental Science, Agricultural and Bio-systems Engineering and Animal Sciences and the Office of Arid Land Studies

From the dairy, the wastewater, containing both solids and liquids, first goes to a solid separator. About 50 percent of the solids are separated out before the water flows to parallel anaerobic and aerobic ponds. The water then is routed to the constructed wetland ponds or cells for further treatment, to approximately secondary water quality standards.

The Rovey Dairy wetland system consists of eight ponds or cells, each 200 ft. by 40 ft., and arranged in two rows of four parallel cells. The tanks are alternately lined with either plastic or clay. Each pair of ponds contains a specific aquatic plant specie, either cattail, one of two types of bulrush, or giant reed.

Researchers can direct the wastewater to a single cell or a combination of cells to test water treatment effectiveness. Since there are two sets of wetland cells, one lined with clay and the other with plastic, and each set of cells is made up of four separate cells, each with different species of plant, an operator can direct the wastewater through varied treatment paths.

Research possibilities become even more numerous since wastewater, after passing through a particular treatment process (e.g., a clay-lined pond with cattails), then can be mixed with water that passed through a different treatment process (e.g., plastic-lined pond with bulrushes) and be tested or even treated with yet another treatment process (e.g., clay-lined pond with reeds) before testing.

Along with determining the quality of water in the ponds, the researchers also are studying infiltration characteristics of the plastic or clay linings. Neutron probe access tubes are installed beneath the ponds, with three tubes under each row of four parallel ponds. The probes are in a horizontal pattern and transverse to the length of the pond. This allows water seepage to be determined along the length of the ponds, at different points in the treatment process.

When saturation or near-saturation points are detected beneath the

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wetlands, suction samplers will extract water samples to determine water quality. Researchers then will be able to better evaluate its suitability as incidental recharge. They also will determine where in the flow of the water maximum treatment is occurring and what residuals are coming out. Researchers also are interested whether the linings will self-seal as the interstitial pore spaces of the soils become clogged with organic material and microbial mass. This subsurface study is one of the more innovative components of the project.

Wetlands-treated dairy wastewater has several uses in dairy operations depending upon its quality. According to regulations nonpotable water cannot come into contact with the milk, milking process, milking equipment, or inside the milking parlor. Treated water, however, can be used to wash the cows outside the parlor or be recirculated to flush wastes.

Another possibility is to recharge the treated water. This would require water treated to at least secondary water quality standards. Project plans now call for acquiring a pilot recharge permit to allow the operation of a small-scale recharge facility. Using the treated water for blending with irrigation water is another possible option.

Project results are expected to be applicable to dairy operations in various areas of the Southwest. Researchers also expect that other industries beside dairies will benefit from the project; for example, the food processing industry, which uses large quantities of water. Also a successful wetland for a diary operation would work for the swine industry.

The researchers also believe this wetland model could serve Arizona irrigators. Water used for irrigation now returns for reuse in the system, with return flows often heavily ladened with various constituents, including chemicals from fertilizers. Water quality could be significantly improved if irrigation water were treated in a wetland before being reused in the system.

As with other constructed wetlands, the Rovey operation will serve as an educational facility. Its target audience consists of people interested in the wastewater treatment process – university graduate students, consultants, industry people, etc.

By involving a broad range of interests – university, government and the private sector – the Rovey Dairy project is an exercise in cooperative enterprise. Diverse interests are mutually benefitting from working together.

Constructed Ecosystems Research

Pima County's Wastewater Management Department demonstrated an early awareness of the importance and potential of constructed wetlands technology when it funded an assessment report in the early 1980s. It then built the Constructed Ecosystems Research Facility (CERF) in 1989 and provided research and operations support.

Designed and constructed as a pilot scale research and demonstration facility, CERF provides researchers from the University of Arizona's Office of Arid Lands Studies as well as the departments of Soil, Water and Environmental Science, Hydrology and Water Resources, Chemical and Environmental Engineering, and Civil Engineering a site to evaluate the effectiveness of constructed wetlands in an arid climate.

The facility is located adjacent to Pima County's Roger Road Sewage Treatment Plant and includes six parallel plastic-lined raceways. Five raceways measure 200 feet long, 30 feet wide and five feet deep, with the sixth slightly larger and deeper.

Experiments at CERF at first were concerned primarily with floating aquatic plant systems (FAP). These systems rely on floating rather than rooted plants to treat wastewater pollutants in a constructed wetland. Winter survival ability and treatment effectiveness of water hyacinths and duckweed, two free-floating aquatic weeds, were compared. Research found that duckweed is more frost-tolerant, but water hyacinths are more effective at treating wastewater.

Current research at CERF is comparing the effects of both potable water and effluent on a variety of native and locally available plants, including shrubs and trees. Effluent appears not to adversely affect native vegetation; instead it seems to stimulate its growth. Researchers also are looking at where wetland plants might concentrate some of the materials removed from wastewater; whether, for example, heavy metals would likely end up in plant roots of the leaves.

Recent CERF research is looking at pathogens in constructed wetlands. Researchers are monitoring indicator organisms such as total and fecal coliforms, viruses and pathogens such as *giardia* and *cryptosporidium*. The research is focusing on two questions. How do pathogens enter the system? Possibly wildlife attracted to many constructed wetlands is the source. CERF researchers also seek to answer the question: How effectively do constructed wetlands remove the pathogens from the wastewater?

CERF research also is concerned with increasing the list of plants for use in constructed wetlands. Constructed wetlands generally rely on a few "workhorse" species: bulrush, cattail and reeds. By collecting additional data, CERF researchers are studying the effectiveness of other types of plants such as cottonwoods and willows. CERF, in fact, has taken the lead in adapting trees to a constructed wetland system. The intent is to establish a more complex vegetative community at a constructed wetland site.

Because of its many research and teaching activities, CERF has been a model for much constructed wetland activity in Arizona. Many designers of constructed wetland facilities and engineers have visited CERF to learn about constructed wetland operations in an arid region.

(Tours of the CERF can be arranged by calling 520-293-2103.)

Varied vegetation thrives at CERF wetlands. At bottom left is a floating aquatic plant system with water hyacinths. Next to the hyacinths are two-year-old willows, and cattails are bottom right. Willows and cattails are on a subsurface wetland system. (Photo: Glenn France)

Constructed Wetlands in Arid Lands

Constructed wetlands offer special arid land benefits. In such areas, where an ethic of careful water use prevails, constructed wetlands, along with varied other water strategies, provide the means to more fully conserve and reuse water.

For example, the Sahuarita School District calculated water reuse benefits to be derived from a full-scale constructed wetland. During the school year, from September through May, the district produces a daily average of 51,000 gallons of wastewater. The wetlands could treat this wastewater to provide 21 acre-feet of treated water. With approximately 15 acres of turf to irrigate, using about 50 acre-feet of water per year, a full-scale wetland would supply about 40 percent of the district's turf water demand. Other rural school districts could similarly benefit from a constructed wetland.

Many large resorts in Arizona produce from 20,000 to 60,000 gallons of wastewater per day. Such resorts might achieve considerable water savings by reusing wastewater treated by a constructed wetlands to water vegetation and golf courses. The Flagstaff Arboretum's constructed wetland treats from 250 to 1,200 gallons per day depending upon the season. The water is used to irrigate vegetation. Producing a vastly greater amount of wastewater, resorts' water savings would be significant.

Not only do they help conserve water, but constructed wetlands allow "double-dipping." The same body of water, at the same time, is used for two different purposes, wastewater treatment and environmental enhancement. Another example of a double dipping is aquaculture using irrigation water in canals to grow fish. These examples may not represent water conservation *per se*. They are, however, arrangements to make a supply of water go further and as a result are a wise use of water. Using water wisely is a guiding principle for life in arid lands.

Constructed wetlands also serve arid lands in other ways. In wetter regions of the United States, a constructed wetland might be one body of water among many. In contrast, a constructed wetland in Arizona might be the single patch of blue in an otherwise arid landscape. Constructed wetlands therefore attract more attention in arid regions, with their water resource potential likely to be more fully explored and developed.

Developing Wetland Regulations

With the increased use of constructed wetlands, government agencies are concerned with devising appropriate regulations, to protect public health and safety without unduly burdening constructed wetland designers and operators. To contribute to this effort, projects are underway to identify, at the state and federal levels, impediments or barriers to wetland construction.

At the state level, the process began when the Arizona Department of Environmental Quality published in 1995 the *Arizona Guidance Manual for Constructed Wetlands for Water Quality Improvement*. Funded by the U.S. Environmental Protection Agency, the publication consolidated technical and design issues and described case studies of constructed wetlands projects in arid lands. ADEQ uses the manual when reviewing constructed wetland permit applications. The manual also provides engineers and scientists with information about the treatment potential of constructed wetlands.

ADEQ officials organized a workshop to discuss the use of the manual and to identify issues that inhibit wetland construction in Arizona. A Total Quality Improvement team was formed made up of ADEQ staff and others with constructed wetlands experience and expertise to address the concerns. TQI's mission statement was to recommend solutions to regulatory and technical issues related to constructed wetlands.

ADEQ believes the regulatory framework is in place, but some fine tuning is in order to accommodate constructed wetland situations. Part of the problem is that constructed wetlands basically are categorized as wastewater treatment facilities. As a result, both conventional and nonconventional treatment facilities fall under the same set of regulations. ADEQ recognizes the need for regulations that acknowledge some of the unique conditions of constructed wetlands.

For example, a regulatory issue addressed by the committee had to do with monitoring constructed wetlands. Exceedences that show up may be the result of natural processes occurring within the wetland system and may take weeks, even months to correct; whereas, such conditions in a conventional plant could be corrected in a matter of days, maybe hours.

A similar inquiry is taking place at the federal level. Funding from EPA's Environmental Technology Initiative Program is supporting a team of regulators and affected parties to identify, describe, and provide recommendations to resolve constructed wetlands policy and permitting issues at the federal level. Work on the report is in progress. For information about the project contact Bob Bashtian of EPA at 202-260-7378.

Prompted in part by issues arising at the 91st Avenue Wastewater Treatment Plant, the federal effort has an Arizona connection, although the scope of the report is national. Also some common ground is covered between the state and national committees since they share several members. As a result, some cross-fertilization resulted. Other than that, however, the two efforts are separate and distinct.

Conclusion

The use of constructed wetlands to treat wastewater is relatively new. The impressive results achieved thus far have prompted great expectations about the technology and what it can achieve. Yet, as promising as the early work is, it is still early work, representing initial efforts to apply natural wetland processes to the varied and complex wastewater treatment needs arising from human activities.

In response to early enthusiasm, some researchers caution that constructed wetlands will not solve all water treatment problems. They point out that the full water quality possibilities – and limitations – of constructed wetlands are not fully known. Some express concern that the promotion of constructed wetlands may be outrunning the available knowledge and technology. More work needs to be done.

For example, researchers are studying plants for the remediation of radioactive contamination. Yet, much more research will be needed to determine whether plants can be used for this task and to what extent. Also the ability of plants to remove certain chemicals from wastewater still is being studied. Even whether wetland plants should be harvested needs further examination.

The available constructed wetlands information and knowledge is extensive compared to even five years ago, and the database is growing. As more projects are planned and further research conducted, the treatment possibilities of constructed wetlands will be better understood.

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