Designing with Nature: Natural Systems for Wastewater Treatment

by Michael Ogden

There is a revolution taking place in the way engineers and scientists are thinking about nature. We are rediscovering how to work cooperatively with nature, while at the same time learning to apply the powerful physical, chemical and mathematical tools of Western science.

This new way of thinking will have a profound effect on the way we live, produce the "stuff" we consume, and deal with pollution and the environment. Out of this new marriage, we will develop a new science and engineering that requires the cooperation of many disciplines, and at the same time a new ethic.

In July of 1990, we began operation of a waste treatment facility based on this coming together of technology and natural processes at Arroyo Hondo, New Mexico. The Arroyo Hondo Pilot Facility is the culmination of my own transformation as a designer and engineer. That personal journey in many ways parallels the broader change in perception that is shaping, and must continue to shape, our relationship with the natural world.

Sputnik and Dead Fish

When I received my training as an engineer, the physical sciences were preeminent. I was a child of the Sputnik era, and everything I learned during my formal education was based on mathematics, physics and chemistry. In all of those years I was exposed to only one chapter in the biological sciences, and that was on the bacteria, algae and protozoans of the wastewater treatment facility. Those were the years when the engineering profession thought all of our water treatment problems could be solved with physics and chemistry.

Still, I was vaguely uncomfortable with the notion that technology alone had all of the answers. Since my early teens I had been a fairly decent gardener, and my early childhood had clearly not been misspent playing in puddles, streams and ponds. These doubts were deepened by Ian McHarg's landmark book "Design With Nature," in which he suggests that the design process could incorporate the natural world in a way that minimizes the impact of human activity on the landscape.

Then in 1981 I met Jim Lovelock and Lynn Margulis at a small conference where they presented their Gaia hypothesis. Lynn's understanding of the role of bacteria was astounding and has since become the foundation of my work. Jim's comprehensive view of the interrelationship of all life was also revolutionary and suggested to me the theoretical principles upon which my work has been based.

The final player in this transformation was John Todd, an aquatic biologist with some important insights he generously shared with me. One very remarkable summer day, high in the Colorado Rockies, John and I walked along a leaking 6-inch water pipeline and he pointed out how life was springing up around those leaks. We have all seen weeds growing around leaking hose bibs, but what struck me then was the realization that water is life.

I began to read about the role nature plays in cleaning water. Specifically, I began reading everything I could get my hands on relating to the natural biological processes of the pond, marsh and meadow.

As an engineer, I began to realize the meaning and importance of the "bio" in biology. The challenge for engineers was to understand natural processes and learn to work with them, rather than attempting to isolate and dominate them.

The message inherent in the natural order became clear when I returned to the ponds, streams and wetlands I had known as a child. The wetland environment is a highly complex ecosystem that works to purify the planet's water. It is impossible to understand it by isolating the individual elements of the system. The system must be recognized and understood in its entirety.

At the beginning, this was a difficult concept for me to accept. I was continually attempting to find that one analytical device that would tell me everything I needed to know. But the more I watched, the more I understood that the eyes, ears, nose, tongue and fingers could tell me more about a natural system than any collection of instruments.

This does not mean that such things as pH meters and analytical chemistry are useless. They provide useful, even essential, information. But that information is only a part of the picture. An understanding of natural systems comes in the same way that a good gardener comes to understand his or her garden. Because we are part of nature, our understanding must come through our participation in it. We have to get our hands wet and our boots muddy. ***continued on page 6***

This is such a simple idea, yet we have so little training for such a discipline. I began my training by walking the wetlands and watching my "pond"—15 gallons of water in an aquarium in my greenhouse containing the plants, insects, mud, fish and microorganisms of a New Mexico pond. Ignoring the pet store suggestions, I simply let the tank do whatever it was going to do.

The fish survived without food, the snail ate the algae on the tank walls, the plants sent down roots into the sediment, and a steady state developed which lasted for several years without any intervention on my part. When a fish died, I watched it turn white as bacteria began the recycling process. The snails and planaria descended almost immediately to eat the bacteria, the flesh and bones. The entire fish disappeared in two days.

I pondered the question of where it had gone. All the notions of the separation of species became indistinct. It was obvious that the forms in my pond were transitory and constantly being rearranged. All the complex proteins and amino acids are arranged one way to appear as fish, then rearranged to form a snail, or assimilated to become plants.

Principles of Wetlands Design

In nature, everything is used; there is no waste. All of the basic elements are continually recycled. Some cycles are longer than others and some elements are crucial, but everything is used over and over. Industrial societies have created waste because the producers have been separated from the consumers. Waste, as in "wastewater," is only wasted if given to the wrong consumer.

The challenge to the designer is to find those consumers who regard the waste as a resource and to create an environment that encourages their growth. One of the simplest of these natural systems could be used to treat residential waste, so I will begin there.

Wastewater leaving the average household is 99.93 percent water. The remainder is made up of solids. About half of these are organic compounds derived from the plant and animal kingdoms. The other half consists of inorganic compounds such as chlorides, carbonates, ammonia, nitrate, phosphates and sulfates as well as trace quantities of micronutrients essential for bacterial and plant cell growth.

Three different ecologies can be used for treatment: the pond, marsh and meadow. These represent very different plant, animal, bacterial, fungal and protozoan communities. They can be used singly or in various combinations to reach the desired level of water purity.

The process is enormously complex, but most of the hard work has been done for you. These ecologies are approximately 500 million years old and have been the major pathway for recycling organic matter, as well as sulfur, phosphorus, nitrogen and many metals. The informational content of the DNA of the living inhabitants of such a system is beyond comprehension. All of these communities have developed over this time to take advantage of the rich nutrient stream that flows down to ponds, marshes and surrounding meadows.

Recognizing that household wastewater is nothing more than a nutrient rich stream, it is easy to see how to develop a pond, marsh or meadow by simply recreating the hydrological conditions of each. The design of such a system is governed by two basic principles: 1) The organic loading that a given ecology can sustain is an area-dependent function—the volume and concentration of organic materials in the system will determine its size. 2) All natural system processes are temperature-dependent; more area is required in cool weather than in warm weather. These principles may be reduced to formulae allowing the designer to size the system to the volume of water being treated, the organic loading of the water, and the temperature.

Natural systems are solar collectors that use sunlight to drive the whole complex. Algae and plants produce oxygen that is exchanged with the water. This oxygen fuels the bacterial processes leading to the ultimate decomposition and recycling of the organic matter and inorganic nitrogen and phosphorus compounds. (Toxic hydrocarbons and heavy metals found in municipal and industrial wastewater pose a different set of problems than the household waste stream.)

So a good system design would expose the ecosystem to as much light as possible. Designers have used translucent containers, shallow ponds and artificial lights. Temperature can be maintained by covering the whole system with a greenhouse.

Alternately, we can augment the solar generated oxygen and mechanically introduce air into the water. All of these have been used where land is limited and the system area is necessarily smaller than it might be. Creating outdoor wetlands is still the most cost effective solution, if land is available.

More difficult than wastewater is the treatment of septage—the thick liquid found at the bottom of a septic tank. Septage is particularly noxious because it is high in nutrients, solids and smelly gases. The EPA considers septage to be approximately fifty times more concentrated than wastewater when all parameters are considered. It is approximately four percent solids, and as a consequence, very difficult for conventional processes to treat.

Since there is no such thing as waste in natural systems design, septage must be regarded as a resource. Because it is a complex waste stream with a lot of organic and inorganic compounds, we have to understand how best to develop ecologies that will use the "stuff" in septage. Analysis reveals some design problems that are unique to septage:

- Septage is high in solids, like the runoff from a newly plowed field after a spring downpour.
- Ammonia levels of 150 milligrams per liter, not uncommon

The water hyacinths are harvested periodically and composted with the remaining solids (about 10 percent of the amount received).

Created Wetlands/Soils

Next, the water flows into a gravel bed planted with species of wetland plants. A different set of microorganisms, plants and bacteria create new interactions which further purify the water. Finally, the water leaves the greenhouse and goes into another gravel bed, this one planted with different wetland species.

The treated water, about 250 gallons a day, is used to irrigate native and arid land shrubs and trees which form a windbreak. The water is essentially free of solids at this point, but still has some ammonia, nitrate and phosphates—substances that any gardener will recognize as important plant foods. The water also contains small amounts of beneficial bacteria that help plants assimilate these nutrients. Soil bacteria are extremely important in the purification of polluted waters. These bacteria can break down or assimilate almost all of the known hydrocarbons or organic compounds manufactured by modern industry.

The Arroyo Hondo project is designed for a very specific set of problems in a unique setting. But the basic design principles it illustrates could be used to solve other water pollution problems.

- **More ecologies are always better.** A pond-marsh combination is better than either ecology alone. A pond-marsh-meadow is better still.
- **Alternating anaerobic and aerobic environments is better than using only one or the other.** The final environment should be aerobic, however. Aerobic environments are more stable and the output is less likely to damage receiving waters or soils.
- **The more diversity of species incorporated into the design, the more stable and effective it is likely to be.** Monocultures are more prone to disease. Diversity can be likened to the wires of a sieve—the more wires, the finer the sieve. The greater the diversity within the system, the less likely it is that large amount of any one substance will escape into the environment.
- **The ability of natural systems to assimilate organic loading is limited.** The designer must regulate the flow of water, air, temperature and light to assist the natural process.
- **Plants selected must be suited to the ecologies designed into the system.** Beyond that, they must be able to remove the "nutrients" desired. Plants may be selected to remove specific substances. This could also apply to selectively cultured species of bacteria. Species targeted to specific types of waste may be more important in dealing with industrial wastewater.

Plants and animals that meet these criteria may be chosen for their economic value. Papyrus, for example, grows very well in septage and in large scale systems could be harvested to make paper.

A Faith in Life

Making changes to natural systems requires that designers have a faith in life and its ability to adapt to and change the environment, in this case by purifying polluted water. For those who can find this faith, there are some demonstrated advantages to adopting the natural systems approach:

- Natural systems are self-regulating and self-maintaining. They work 24 hours a day, 365 days a year.
- They cost significantly less to build and operate than conventional treatment technology.
- Because they are solar-powered, natural systems use less energy.
- They are able to remove disease-causing organisms, reducing or eliminating the need for disinfection.
- Natural systems control odors.
- Large systems can provide significant habitat for waterfowl and wildlife, and open areas for parks, recreation and nature study. Systems enclosed in greenhouses can become botanical gardens and arks for the protection of endangered species.

Beyond these advantages, we have a responsibility to the planet, a stewardship. The next century will present us with some difficult challenges requiring a new discipline and ethic. It will require people of vision and commitment. Of course there are many different visions possible, but here are a few of my own.

Imagine a municipal wastewater treatment facility consisting of a large greenhouse covering several tens of acres and filled with lush green flowering plants, waterfalls, birds, fish, frogs, salamanders, turtles and any number of other creatures. Except for the initial pretreatment section, this greenhouse could be open to animals and the public. Within this complex we would employ gardeners, botanists, waterfowl biologists, microbiologists, and a few fish and game park rangers to keep the crowds in order.

Alternatively, picture every home owner with a greenhouse containing ponds and marshes used to treat and purify domestic wastewater. In warmer regions a backyard marsh with water trickling under a gravel bed planted with reeds, cattails, iris, daylilies, canna lilies, or any of 5,000 or so species of wetland plants could accomplish the same goal while providing habitat for birds, frogs, salamanders and other creatures of this planet for whom water is life. ◆

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