CONSTRUCTED WETLANDS IN THE SUSTAINABLE LANDSCAPE

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Preface

Wetlands—whether natural or constructed—provide a fascinating setting, teeming with myriad forms of biological life and activity. They have increasingly become recognized for their unique ecological functions in our environment and are the focus of increased research by scientists and interpretive programs by schools, communities, and nature centers.

There has been a corresponding increase in constructed wetlands and their potential to provide an effective, low-cost, natural method of removing pollutants from both wastewater and stormwater. Interest in wetlands extends from students in landscape architecture and environmental engineering programs to the real world of public officials, developers, and private citizens. Unfortunately, although there have been numerous seminars and conferences on the subject, with technical reports, proceedings, and books published almost on an annual basis, most of these publications have been in the technical realms of biology, engineering, and wetland chemistry. While this context provides a very useful and solid foundation in advancing knowledge of constructed wetlands, there has been a noticeable lack of attention to some of the most intriguing aspects of constructed wetlands—their aesthetic, landscape, wildlife habitat, and other multiple-use values. This volume is intended to provide an initial basis for understanding the unique potential that constructed wetlands can provide to integrate water renovation processes with other functions that are public amenities rather than eyesores.

The past few decades have witnessed many environmental shifts in both public values and government policies. Unfortunately, some of the most well-intended policies and regulations directed at cleanup of polluted waters have coincided with a virtual dissolution of programs that previously provided grants for new or upgraded wastewater treatment facilities to assist communities in meeting these regulations. The U.S. EPA's Construction Grant Program, which was phased out in the 1980s in favor of state revolving loan programs, provided money to promote innovative and alternative wastewater treatment systems. A variety of constructed wetlands were funded under this program, and when it was phased out, the momentum was somewhat lost. The Clean Water State Revolving Fund (CWSRF) is a loan program run by states with seed money from the EPA and other sources. This program has been the major source of funding for wastewater treatment projects, including individual homeowner loans. There are additional funding sources for on-site treatment systems that vary from state to state, and some of this funding supports pilot projects utilizing constructed wetlands in several parts of the country.

Another source of support, at a smaller scale, for grants and assistance to help communities identify, install, and monitor alternative wastewater treatment systems is the National Onsite Demonstration Project (NODP) begun in 1993 and administered by the National Small Flows Clearinghouse (NSFC), an EPA-funded unit at West Virginia University. A constructed wetland system, among others, is being tested to treat restroom wastewater at a county park site in West Virginia

The U.S. EPA established the Small Flows Research Program in 1973 to help support viable alternative wastewater treatment systems in areas where site conditions precluded the use of conventional systems. The NSFC was created under the Clean Water Act to assist small communities with their wastewater-related needs by collecting and disseminating information. *Small flow* refers to a facility with a design capacity of 1 million gallons per day or less, or to wastewater typically generated by 10,000 or fewer people. The NSFC publishes an excellent newspaper-format periodical; offers more than 600 different manuals, pamphlets, and videotapes—many addressing constructed wetlands; and offers technical assistance and outreach by means of workshops, seminars, and referrals. Their toll-free number is 1-800-624-8301, and their Web site is at http://www.nsfc.wvu.edu.

In addition, of course, at various times grants are available at state and regional levels, such as the assistance for *colonias* water and wastewater infrastructure offered by the Texas Water Development Board in border counties; Farmers Home Administration grants; and other sources of limited assistance. However, in the absence of grants, which are extremely limited in both size and availability, communities faced with increasingly stringent wastewater and stormwater treatment requirements are typically able to receive only loans—not grants—for the required improvements. This situation, which typically results in the necessity to raise sewer rates, will undoubtedly become worse for local communities, mandating consideration of the most cost-effective means of treating wastewater and other polluted water. Not only the original capital costs but also the long-term costs of operation and maintenance must be given even more attention than before.

This situation has given rise to widespread interest worldwide in utilizing 'natural systems' for wastewater treatment. Although all wastewater treatment systems, even those within the framework of 'high-tech' advanced treatment systems, utilize natural biological processes to some degree, the development over the past several decades of a knowledge base regarding wetlands processes and the ability of constructed wetland systems to renovate polluted waters has become quite sophisticated. Constructed wetlands exist in Great Britain, Canada, the United States, Mexico, India, South Africa, Brazil, Australia, and many European countries ranging in size from small single-family residential systems to major facilities treating up to 12 million gallons per day of wastewater. These systems are becoming more acceptable to local and regional regulators as the data on their performance continue to prove the cost-effective nature of their operation.

One of the most interesting aspects of the field of constructed wetlands is the multidisciplinary nature of the subject. From the very beginning, research and development within this field has attracted an admirable collection of experts ranging from chemical engineers, aquatic biologists, ecologists, and wildlife specialists to landscape architects, civil engineers, and others. The very nature of wetland processes is fascinating, and as one person put it, ''addictive'' the more one delves into it! At this point, the subject is in need of integration with the professional disciplines most responsible for the process of planning our communities and designing the constructed environment. To that end, we hope to engage the interests of architects, landscape architects, planners, developers, and public officials who have a clear responsibility to consider the long-range environmental costs and benefits of their efforts and decisions. This volume will therefore focus on the multiple benefits and uses of constructed wetlands and the means by which they can be successfully integrated with other community amenities such as park and open space systems, schools, museums and nature centers, wildlife refuges, and other elements of the built environment.

Aquatic plants are not unique in their capacity to provide benefits to humans and their constructed environment. Human history is so closely connected with plants and the development of their beneficial uses, ranging from food and fiber to medicines and shelter, that the Western dissociation from folk knowledge of plants over the past century appears to be an unfortunate anomaly of a culture more interested in comfort and consumption than in a deeper connection with natural processes. This aspect of Western society's recent history is undergoing a profound reorientation that is being manifested worldwide. Few countries or societies anywhere now welcome industrial development, resorts, or other high-impact projects with open arms, and there is increased interest in low-tech solutions to many of the development and pollution problems around the globe. *Sustainability* has become a key word and a critical objective for new development, and is written into the guidelines of the World Bank and most other international lending institutions for assessing new projects.

Today it is increasingly problematic to isolate or subdivide all of the various elements associated with new development and with improvements to our existing environment. Even though this volume has taken on the task of presenting one technology only—that of utilizing low-energy natural aquatic systems to renovate polluted waters—we have tried to emphasize the total interdependency of the various disciplines dealing with the built environment. At a time when most academic programs are becoming increasingly specialized—or, as the pundits have put it, ''learning more and more about less and less''—the most pressing need in today's world is for more meaningful integration of diverse disciplines and areas of knowledge.

Landscape architecture is possibly the only profession that has traditionally embraced this integrative function. This stance has given the profession with a solid foundation to provide leadership on large multidisciplinary projects involving a sensitive inventory and assessment of both cultural and natural resources. Central to this role is the willingness to engage the full range of appropriate specialists and the ability to coordinate their work with minimal preconceptions.

The development of a sound corpus of theory on the development of sustainable landscapes, based on the work of Ian McHarg, Michael Hough, John Lyle, Robert

Thayer, and others, has placed landscape architecture in the lead within the field of environmental design. Unfortunately, architects are generally obsessed with theory and trendy styles, typically ignoring the myriad environmental factors that comprise a particular setting and deserve an appropriate and sensitive response. Planners, with few exceptions, have virtually abandoned the field of site planning and design, and have certainly not been responsible for the development of a body of theory encompassing guiding principles for their profession. What is now called *new urbanism* is not really new; it has been defined primarily by architects, with little reference to environmental factors.

Engineers have been strongly criticized for creating visual ''monsters'' that in many cases are more a result of politics, funding, and regulations than of incompetent or insensitive design. But it can fairly be said that the engineering profession as a whole has not been in the forefront in developing innovative approaches to handling stormwater runoff, parking area and roadway design, or other elements of site development within their domain. Most of the more creative aspects of stormwater detention, biofiltration, and so on have arisen from the involvement of landscape architects in the development process, often in conjunction with progressive developers of housing and commercial projects who are highly concerned with environmental issues and strongly commitmented to the principle of sustainability.

An interesting example of the emergence of a new ethic within the engineering profession and government agencies is provided by the U.S. Army Corps of Engineers. This agency, more than any other within the federal bureaucracy, was responsible for projects with devastating impacts on the natural environment. In an interesting change of direction, this agency, which has essentially run out of work in terms of new dam construction, has taken on the work of restoring wetlands habitats and re-creating the former path of the Kissimmee River in Florida, which involves backfilling the canal the Corps channeled over thirty years ago. The Kissimmee was channelized in the 1960s by the Corps to control flooding and provide continuous navigation. A 103-mile meandering river was straightened into a 56-mile canal that drained the surrounding wetlands and heavily impacted wildlife and other natural resources both in the immediate area and in the Everglades. The restoration plan, developed by the South Florida Water Management District and the Corps, is estimated to take fifteen years and cost $350 million.

There are other positive moves that recognize the importance of developing a more integrated biological approach to management of pollution problems at many levels. The objective of this volume is to further the understanding of the alternatives that deserve proper evaluation within the framework of sustainable landscapes.

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The Concept of Sustainable Development

> There is nothing more difficult to take in hand, more perilous to conduct, or more uncertain in its success, than to take the lead in the introduction of a new order of things.
>
> —Niccolo Machiavelli (*The Prince,* 1532)

CONSTRUCTED WETLANDS AS SUSTAINABLE DESIGN

For at least fifty years, conventional wisdom has mandated the development of extensive wastewater collection systems directed to a centralized treatment plant. More attention is now being given to the benefits of a decentralized approach to treating wastes at their source—*point source* treatment, as it is called when related to industrial wastes normally dumped into storm drains. Such an approach also has value when applied to sewage wastes and is more in line with the philosophy of *sustainable development.* In many situations, a decentralized system of treating sewage wastes, potentially with constructed wetlands, can provide not only a more economical and energy efficient means of achieving treatment objectives, but also a resource in the form of reclaimed water available for landscape irrigation or creation of wildlife habitats. Such an approach may have value both in new developments remote from existing wastewater treatment facilities and in areas in need of upgrading or retrofitting septic tank and leach field systems that are polluting the groundwater.

Conventional means of treating wastewater typically involve rather unattractive industrial-looking facilities surrounded with chain link fencing. They usually have no functions except those related to treating wastewater and do not add to the visual quality or value of the surrounding area. In fact, new conventional facilities are extremely difficult to locate and generally have a negative image. There is now at least belated recognition in some parts of the country of the importance of both architectural quality and artists in the process of designing wastewater and other infrastructure projects. While the focus of this book is on decentralized, or on-site, treatment of wastewater and stormwater, we recognize that there is little choice in many communities that have already committed to centralized systems for many years. The best option for these communities and cities is to consider carefully the visual impact of any new expansion projects, and plan for public interface and education to be programmed into any new projects from the beginning. One notable recent project is the Oceanside Water Pollution Control Project in San Francisco, designed by the firms CH_2MHill, engineers, with the architectural design leadership of Simon Martin-Vegue Winkelstein Moris (SMWM). Described as a ''conceptually innovative and environmentally sensitive wastewater treatment facility,'' the 45-acre project site is located on the Pacific coast and surrounded by public lands such as the San Francisco Zoo and the Golden Gate National Recreation Area. Concerns over the potential impact of the project led to a design with at least two-thirds of the building area underground, in an artificial canyon, with access through a series of tunnels. The facility met the objectives related to visual impact while establishing a milestone by carefully providing a setting: a walled, terraced, semipublic garden attractive to visitors who will tour the plant. Cathy Simon of SMWM feels that the architecture and site design of this project will be part of the education process for the public and states that ''at the end of the twentieth century, an ecologically responsible bulding project can also be a resonant public place, capable of interpreting an industrial process of great importance to people's lives.''

There have been other projects that have gone even further to integrate the interpretive process, involving artists and landscape architects in central roles in collaborative teams. These projects are described in detail in Chapter 9.

Sustainable design has become a worthwhile objective of our society and has in fact been adopted as a goal of many professional design associations. Within academia, there is an increasing awareness of the principles of sustainability, and units such as the Center for Sustainable Communities in the College of Architecture and Urban Design at the University of Washington have been established to foster research, coordination between programs, and technology transfer.

John Lyle and others at California State Polytechnic University in Pomona have developed the Center for Regenerative Studies on 16 acres at the campus to provide a setting for research, education, and demonstration of *regenerative technologies.* With twenty residents in the first phase, the community is planned to increase to ninety, providing opportunities to grow food, recycle waste, generate energy, and, in general, ''learn by doing.''

While the term may have different meanings for different people, one appropriate definition, as adopted by the National Park Service, is: ''. . . Sustainability as related to park planning, design, and development means meeting present needs without compromising the ability of future generations to meet their own needs. Sustainability minimizes the short and long term environmental impacts of development activity through resource conservation, recycling, waste minimization, and the utilization of energy efficient and ecologically responsible materials and procedures for construction.''

Organizations representing design professionals have also made serious efforts to assist their members in assessing the environmental impacts and cost/benefits related to total life cycle costs of various materials. The American Institute of Architects (AIA) is to be commended for their intensive effort to provide a basis for selecting products and materials that have the least impact on the environment;

the organization now publishes the *AIA Environmental Resource Guide,* with quarterly installments offering detailed information on material life cycle assessments, case studies, and other information.

Wetlands have become a topic of increasing interest around the country, both to governmental regulators and to scientists, and the nature of wetlands processes has only recently begun to be understood. Constructed wetlands are increasingly being recognized as a relatively low-cost, energy-efficient, natural means of treating sewage, agricultural and industrial wastes, and stormwater runoff while at the same time offering the potential for multiple benefits. Among these benefits are the potential for integration of constructed wetlands into park and recreational systems, the wildlife habitat they provide, their aesthetic qualities, and the superior quality effluent that they produce, which can be recycled for landscape irrigation or impounded in an attractive and educational pond of value in attracting wildlife while also conveying information on wetlands processes.

In many situations, constructed wetlands can be designed to rely almost entirely on natural processes and gravity flow, thus conserving energy by minimizing or eliminating the use of pumps and mechanical equipment. In addition, the maintenance required is considerably less than with a conventional system, and the entire treatment ‘‘train’’ often has the ability to operate for long periods with no human intervention whatsoever. These characteristics generally place constructed wetlands in the sustainable landscape category, particularly due to their ability to provide multiple functions and benefits at low cost and with low environmental impact.

The following is excerpted from USEPA, 1988, p. 1:

> The trend over the past 70 years in the construction of water pollution control facilities for metropolitan areas has been toward ‘‘concrete and steel’’ alternatives. With the advent of higher energy prices and higher labor costs, these systems have become significant cost items for the communities that operate them. For small communities in particular, this cost represents a higher percentage of the budget than historically allocated to water pollution control. Processes that use relatively more land and are lower in energy use and labor costs are therefore becoming attractive alternatives for these communities. . . . The interest in aquatic wastewater treatment systems can be attributed to three basic factors:
>
> 1) Recognition of the natural treatment functions of aquatic plant systems and wetlands, particularly as nutrient sinks and buffering zones.
> 2) In the case of wetlands, emerging or renewed application of aesthetic, wildlife, and other incidental environmental benefits associated with the preservation and enhancement of wetlands.
> 3) Rapidly escalating costs of construction and operation associated with conventional treatment facilities.
>
> . . . Where natural wetlands are located conveniently to municipalities, the major cost of implementing a discharge system is for pumping treatment plant effluent to the site. Once there, further wastewater treatment occurs by the application of natural processes. In some cases, the wetland alternative can be the least cost advanced wastewater treatment and disposal alternative.

At the time when this Environmental Protection Agency (EPA) report was prepared, examples of wastewater conveyed into existing natural wetlands were more common than constructed wetlands, and the positive attitude reflected in the report was an indication of the substantial water quality improvement that had been monitored for many years within these natural wetlands. With increasing emphasis on protection of natural wetlands, this practice came to a logical halt as more information was developed on the design of constructed wetlands, which offered much more control and better opportunities for monitoring. In a number of later reports and studies, the EPA noted these same advantages in comparative life-cycle studies of constructed wetlands and advanced wastewater treatment methods demonstrating that wetlands were more economical given the availability of land at a reasonable cost.

LANDSCAPE ECOLOGY

As a basis for a theory of sustainable design on a regional or site-specific basis, landscape ecology would ideally provide designers with a body of knowledge capable of being employed, in some capacity, as a general framework. However, although landscape ecology has grown in stature through research and publications, it remains a cumbersome assemblage of theory and data from myriad specialized disciplines from the natural sciences combined with an overlay of cultural characteristics. In an ideal world, landscape ecology would help define and support the role of constructed wetlands in any setting, and would assist in efforts to mesh seamlessly with adjacent land uses and to integrate with greenways, wildlife corridors, and buffer zones.

Budgetary realities do not normally allow in-depth ecological inventories of a wider area to be undertaken as part of a constructed wetland project. Typically, however, abundant information is already available on the soil characteristics, slopes, climate, vegetation, and other aspects of a particular location to provide a reasonable basis for developing an understanding of localized landscape ecology.

One of the most useful and concise guides for designers is *Landscape Ecology Principles in Landscape Architecture and Land-Use Planning* (Dramstad et al., 1996), a slim volume with good diagrammatic illustrations of the principles underlying the concepts of edge habitat, patches, fragmentation, corridors, connectivity, and mosaics. Given the diversity of conditions affecting any localized site, especially those that are artificial, it is impossible to develop a ‘‘cookbook’’ equally applicable to all locations. Designers need to be sensitive to the long-range impacts of their projects, and greater emphasis on landscape ecology can provide a fuller understanding of both potential problems and opportunities for expanding the integrative functions of a constructed wetlands project.

THE SUSTAINABLE LANDSCAPE MOVEMENT

The father of the sustainable landscape, in terms of being the earliest to espouse the principles now underlying the philosophy of low-impact, environmentally sound site development, is Ian McHarg. His book *Design with Nature* has had a profound impact on the way we look at the land inventory and development process and has provided the intellectual basis for many of the more recent computerized geographic information systems (GIS) databases that are now widely employed as the basis for urban and regional land use and planning decisions. Even as these systems become more widely employed, however, one cannot ignore a finer level of specific detail, the character or genius loci of any particular site, which is impossible to digitize and classify into neat categories at the cell level of any GIS system. There is a very real danger of the technique or the technology becoming an end in itself rather than a useful tool that is carefully and judiciously employed primarily for developing broad classifications to assist in planning efforts. Potentially, such a system can be used as a convenient but superficial means of justifying improper development by an inaccurate representation of computerized models as the most ''scientific'' and unassailable source of information. Most of us who have had extensive experience with mapping of all types, and at all levels of detail, are surprised every time we set foot on a site on which we assumed we had all the relevant information; there are many special elements in any landscape, ranging from a single tree of great character to unique rock outcroppings or geologic anomalies, that are impossible to assess with aerial photography and GIS systems. That having been said, however, GIS systems do provide a remarkably efficient means of storing and retrieving information on ownership, vegetation, wildlife habitat, geology, slopes, zoning, and a host of other attributes that can provide at least a gross understanding of the characteristics of large areas. The weakness is evident when one needs more detailed information on specific smaller areas, including types of information neither readily measurable nor easily quantified for storage in any computerized mapping system.

The seminal project incorporating McHarg's concepts of careful and thorough analysis of environmental conditions as the basis for developing a sound plan was Woodlands, a planned community north of Houston, Texas (Figure 1.1). The level of care exercised by the developers of this community has not been adequately conveyed in most accounts of the project and has rarely been equaled since. The project was started in 1971, and the site development principles developed by the firm Wallace, McHarg, Roberts, and Todd as environmental consultants addressed the issues of varying soil permeability related to carrying capacity and potential for stormwater infiltration; surface management of stormwater; and creating a suitability model for developing the most appropriate portions of the site while retaining open space and stormwater management areas as dictated by the site and soils inventory.

Another great pioneer in the field of sustainable landscapes is Joachim ''Toby'' Tourbier. While a professor in the Department of Landscape Architecture at the University of Pennsylvania, Tourbier became interested in biological means of controlling water pollution in the early 1970s. In 1976, he became aware of the work of Kathe Seidel at the Max Planck Institute in Germany, along with the work of others, and organized the first major international conference on the subject of biological, low-tech methods of stormwater and wastewater renovation. In a more recent effort, *Lakes and Ponds*, a publication of the Urban Lands Institute, Tourbier and Richard Westmacott of the University of Georgia present a number of projects involving constructed stormwater wetland ponds and the biological processes involved (Tourbier, 1992).

Since then, other authors have presented a more fully developed philosophy of human impact on the landscape and on urban systems in books such as *City Form and Natural Processes* by Michael Hough of Toronto; *Regenerative Design for*

Figure 1.1 *Woodlands, Texas: Natural infiltration area (Wallace Roberts & Todd).*

Sustainable Development by Prof. John Lyle of California State Polytechnic University, Pomona; and *Gray World, Green Heart* by Prof. Robert Thayer of the University of California at Davis.

Michael Hough's book, published in 1984, presented the first integrated philosophy of bringing environmental values into the urban landscape and presented a strong, well-developed case for biological diversity within urban landscapes that has not been given its proper recognition. In a later volume directed at restoring a sense of regional identity to the landscape (Hough, 1990), the author stated succinctly the connection between sustainability and an understanding of natural systems:

> Sustainability involves, among other things, the notion that human activity and technological systems can contribute to the health of the environments and natural systems from which they draw benefit. This involves a fundamental acceptance of investment in the productivity and diversity of natural systems. (p. 193)

Pointing out that the development of a new environmental ethic of sustainability requires a major shift in attitudes, Hough points out that

> the principle of investment in nature, where change and technological development are seen as positive forces to sustain and enhance the environment, must be the basis for an environmental design philosophy. Its principles of energy and nutrient flows, common to all ecosystems when applied to the design of the human environment, provide the only ethical and pragmatic alternative to the future health of the emerging regional landscape. (p. 194)

It is interesting to note that these books, by landscape architects, have established a genuinely new theory of sustainable landscape development in a profound departure from all past design theory, which was primarily based upon aesthetics. By laying out this new framework, an ecological basis for design, they—along with others—have clearly established a foundation for practice of landscape architecture that has no counterpart in the field of architecture or city planning. In fact, both of these allied professions need to better integrate into their own worldviews the principles of sustainable landscape development to bolster their own less developed—and more static—philosophy of land planning. As John Lyle stated, ‘‘In the perspective of history, we might even view this predictive approach as a new phase in the shaping of the physical environment. Looking back, we can see at least three earlier phases that brought us to where we are now.’’ Lyle goes on to describe, first, the *instinctive* phase, which involved building without forethought but with instinctive insight—witness the complexity of a spider web or beehive. The second phase involved the development of tradition and the application of accumulated knowledge that often achieved an admirable environmental ‘‘fit.’’ The third phase was the *form-making* phase, typified by the application of reason, invention, and creativity illustrated on paper prior to construction. The emerging phase that Lyle describes as the one we are beginning to create and participate in involves *predictive adaptation*, which utilizes the skills developed in earlier phases and, in addition, develops our abilities to store information and predict and plan for adaptive change. Lyle warns us not to become too smug about our perceived technological abilities, quite properly recognizing that the unexpected can always happen.

BIOSPHERE 2

The earth represents Biosphere 1; Biosphere 2, by contrast, was originally developed as an experimental 3-acre glass-domed complex in the Sonoran Desert of Arizona designed to emulate the earth itself (Figure 1.2). The Biosphere 2 project achieved considerable publicity—both positive and negative—related to its experiments placing humans in a closed environment comprising miniature oceans, marshes, rain forests, and 3,800 species of animals and plants. This project was advertised as the largest self-sustaining ecosystem in the world, but in reality it represented from its inception an example of bad science combined with almost unlimited financial resources. While the concept of constructing a wide range of miniature ecosystems within a huge greenhouse in Arizona had considerable potential from the very beginning as a research and educational facility, the concept of the experiment as representing any type of model for space colonies (the underlying principle guiding the entire project) was always farfetched.

Figure 1.2 *Biosphere 2—view of the facility (Decisions Investments, Inc.).*

The designers of the facility recognized the need to process the system's wastewater naturally and to recycle both the water and the nutrients for use in a closed system. Drawing from the bioremediation experiments of Billy Wolverton at the NASA Stennis Space Center in Mississippi (Wolverton, 1989), the facility's designs included a wastewater treatment and recycling system capable of handling the sewage of up to ten people and their domestic animals by utilizing wetlands in a series of tanks. The first tank in the series contains a gravel substrate with an overlay of soil planted with cattail, bulrush, reeds, and tall grasses. This unit is essentially a subsurface flow unit, which then feeds into a second tank also planted with aquatic plants but with exposed water in open, meandering channels. The third tank is more of a pond and has small islands; from there, the water is pumped into a utility water tank, where it is stored for use in irrigating agricultural crops. All three tanks together take up only about 300 square feet and process all of the wastewater from the toilets, showers, and sinks produced by the humans occupying the structure (Figure 1.3).

The effluent, following anaerobic digestion in a series of three 1,900-liter septic tanks, follows a meandering path through the three lagoons by a series of baffles. The perforated pipes supplying effluent from the septic tank to the primary lagoon had to be switched routinely to a second line to allow clearing of sludge and plant roots. It is worth noting that among the many luxuries that the eight original biospherians had to forgo was toilet paper to avoid overloading the wastewater treatment system. A separate marsh-type unit was installed to treat laboratory wastewater and all of the drainage from the Biosphere 2 machine shop. Potable water is produced through condensation in the ten air handler units in the habitat's basement. This system is capable of producing more than 9,500 liters per day and is either disinfected with an ultraviolet unit for use in human consumption, sanitation, and food preparation or mixed with the agricultural irrigation system water for watering rice paddies, vegetable plots, worm beds, fish culture tanks, and house

Figure 1.3 *Biosphere 2—treatment tanks (Decisions Investments, Inc.).*

plants. The two final water products from the recycling system are high-purity condensate for human and animal consumption and utility water of greatly varying quality for crop irrigation, animal pen washdown, and toilets. The eight toilets are flushed with the utility water and equipped with condensate water–supplied bidets that allow the elimination of toilet paper. There are also twelve sinks, including the kitchen and laundry, seven showers, and two washing machines, all supplied with condensate water. The average daily production of wastewater when occupied is 1,500 liters per day.

A number of problems beset the Biosphere 2 experiment during its first several years, including a buildup of gases such as nitrous oxide and carbon dioxide, excess salts in the recycled water system, and other conditions that forced the new managers to ''flush out'' the entire system in 1994, providing a ''reset'' to allow the initiation of a revamped scientific focus with a terrestrial emphasis and fewer theatrics of questionable scientific value. Some of the first experiments under the new management, which includes a consortium of scientists from Harvard and Stanford universities, will focus on a study of photosynthetic ranges of a wide range of plants with varying carbon dioxide levels. Interestingly, it was determined that excess organic material in the structure's soil set off an explosive growth of oxygen-eating bacteria, which produced carbon dioxide, much of which was absorbed by the 110,000 square feet of exposed concrete that lines the structure's interior.

THE CENTER FOR MAXIMUM POTENTIAL BUILDING SYSTEMS

Better known as ''Max's Pot,'' the Center for Maximum Potential Building Systems was established by Pliny Fisk III in 1975 in Austin, Texas, as a nonprofit education, demonstration, and research organization to examine sustainable design and construction practices to meet the needs of individual home builders, as well as planners and developers. One of the Center's showcase projects is a demonstration farm complex in Laredo, developed in cooperation with the Texas Department of Agriculture, that highlights recycled and agriculturally based building materials. Another is the Green Demonstration Building Project in Austin and Laredo. Several of the demonstration projects have integrated on-site constructed wetland wastewater treatment systems and utilize solar energy, straw bale construction, and other low-impact technologies (Figure 1.4). One of the major applied research projects at the Center is the investigation of the potential for a wide variety of earthen materials for construction, including adobe, caliche, laterite, flyash, natural pozzolan cements, and alumina clay brick.

One of the Center's most interesting innovations is based upon the recognition that the majority of the world's population lives on or near an ocean coast and that reliable sources of fresh, potable water are in decline. Because a large percentage of potable water in most industrialized countries is flushed down the toilet, the Center designed a method for utilizing salt water, pumped from a shallow on-site well, for toilets combined with a constructed wetland treatment system for the Center for Wetland Studies, a facility in Baja California Sur, Mexico, operated by

Figure 1.4 *Wetland treatment cell, Center for Maximum Potential Building Systems (Center for Maximum Potential Building Systems).*

the School for Field Studies (Figures 1.5 and 1.6). Using a gravity flow system, standard septic tanks with effluent filters are used for primary treatment. From there, the outflow feeds into a subsurface flow constructed wetland planted with halophytes, or salt-tolerant plants, that are also hydrophytes capable of withstanding inundation. One of the plants utilized is giant reed, or carrizo *(Arundo donax)*.

Figure 1.5 *Master plan for SFS campus with wetland treatment systems (Center for Maximum Potential Building Systems).*

Figure 1.6 *Concept for a saltwater system, Baja California Sur, Mexico (Center for Maximum Potential Building Systems).*

There are four wetland treatment cells: two to treat nonsaline graywater from the kitchens, laundry, and bathhouse; one to treat saline wastewater from toilets; and one to treat a mixture of saline toilet wastewater and nonsaline sink, bath, and shower water. Some of the saline wastewater effluent is to be used to water ornamental halophyte plants installed to provide privacy screens between student cabins. Constructed in 1998, this project should prove to be a valuable experiment worthy of exploring in more detail in other areas as performance data are collected (Figure 1.7).

CONSTRUCTED WETLANDS AND PERMACULTURE

As stated by Mollison (1990, p. ix), ''Permaculture (*perma*nent agri*culture*) is the conscious design and maintenance of agriculturally productive ecosystems which have the diversity, stability, and resilience of natural ecosystems. It is the harmonious integration of landscape and people providing their food, energy, shelter, and other material and non-material needs in a sustainable way. Without permanent agriculture there is no possibility of a stable social order.'' This is a high-minded,

Figure 1.7 *Baja California Sur project—student cabins (Center for Maximum Potential Building Systems).*

sensitive, and commendable philosophy to which one can hardly object; in fact, constructed wetlands fit in admirably with the overall permaculture philosophy. There is a problem, however, with the widespread proliferation of overnight permaculture ''experts'' whose overall knowledge of the environment is rather shallow. One of the unfortunate and dismaying characteristics of this otherwise sensible movement is the fact that it has become virtually a cult, with a high level of zealotry among its followers.

Very few individuals are capable of developing an in-depth understanding of more than one significant ecosystem or local environment, let alone the myriad range of ecosystems existing worldwide. Permaculture represents a set of concepts that are entirely laudable. What permaculture does *not* represent is a grand, innovative, new vision or philosophy of development and management of the land and its resources. None of the concepts making up permaculture are new or original; virtually all of the ideas of energy conservation—small-scale integrated food production, capturing of roof and other stormwater runoff, recycling, use of indigenous plants, and so on—have been around for centuries, with more emphasis within some cultures and at some periods of time than others.

This having been said, it is fair to assess the emergence of a high level of interest in concepts of conserving water, soil, and biodiversity as a very positive change in our global outlook. Specialists in every field, from aquatic biology to civil engineering, are more keenly aware of the interrelationships between consumption, conservation, recycling of resources, and stewardship of our land, and more serious research and interdisciplinary interaction are now taking place than ever before.

Our urban landscapes have suffered in this century in failing to achieve a connection with the natural world. The people most responsible for the design and development of urban areas have been builders and developers, engineers, politicians, planners, and architects—probably in that approximate order. Although landscape architects have had an impact on parks and streetscapes, they have typically been involved only after the basic framework was already established by others. Notably absent have been biologists, ecologists, and other natural scientists, whose perspectives are sorely needed to connect the urban pattern in a sensitive way to the natural world in which it resides. As John Lyle points out, the real challenge is to ''get sustainability out of the fringe and into the mainstream where these ideas have to be if they're to have any effect on this society.''

BIOREMEDIATION AND PHYTOREMEDIATION

The field of bioremediation—and, more specifically, *phytoremediation*—is one more area of endeavor closely tied to the principles of constructed wetlands for water renovation and the broader principles of sustainability. The scientific community appears to be on the threshold of a world of incredibly interesting discoveries on specific plants, bacteria, fungi, and algae, and the ability of specific species or strains to remove and break down a wide variety of contaminants.

Researchers at Ohio State University developed a method of removing cadmium from wastewater by using bacteria called *Zooglea ramigera* trapped in tiny artificial beads. With this method, this heavy metal is removed from effluent before it leaves a manufacturing plant to enter a sewage system. At the University of Hawaii, researchers report that the fungus *Penicilium digitatum* can absorb uranium from solutions of uranyl chloride. Another interesting recent event is the development by scientists at the University of California at Riverside of a method to speed the action of several types of natural fungi in converting selenium into a harmless gas. In tests at the Kesterson National Wildlife Refuge, it was demonstrated that the fungi were able to remove as much as 50 percent of the selenium in as little as four months.

There are undoubtedly many other efforts underway that may provide a wide menu of options for using specific bacteria and fungi in combination with wetland treatment systems to provide wastewater renovation—at least in smaller systems—superior in quality to that of most tertiary-level mechanical treatment facilities.

In research laboratories, academic institutions, private bioremediation companies, and other facilities, intense efforts are underway to develop specialized bacteria and fungi to clean up aquifers, toxic dumps, and oil spills. Methane-eating bacteria have been discovered and developed that produce enzymes capable of degrading more than 95 percent of contaminants such as vinyl chloride and other poisons into salt. Bioremediation techniques utilizing bacteria are cheaper than incineration and do not produce a toxic ash. Firms specializing in this work, such as Ecova, Inc., Biotrol, CAA Bioremediation Systems, and Environmental Protection North of Germany, have nurtured specialized bacteria that have been used to degrade oil, benzene, toluene, creosote, phenol, and herbicides at various sites around the earth, with high rates of success. Even resistant compounds such as polychlorinated biphenyls (PCBs) have been successfully degraded with specialized bacteria. Now there are even products on the market designed for homeowners and others who would like to remove oil, gas, transmission and brake fluids, and solvents from paving by using bacteria. The microbes are combined with a clay or vegetable extract and remain inert until activated.

Under the general heading of phytoremediation (*phyto* means ‘‘plant’’), teams of researchers at Brookhaven National Laboratory, the U.S. Army Corps of Engineers Waterways Experiment Station (WES) and the National Risk Management Research Laboratory of the U.S. EPA are at several locations testing and documenting the appropriate uses of phytoremediation in constructed wetlands for its ability to degrade TNT and cyclonite contaminants in groundwater. They have determined that the best performance was achieved with elodea, sago pondweed, and water stargrass (Best et al., 1997). In the future, there may be opportunities for serious research on the development of specialized microbes that may enhance the ability of constructed wetlands to degrade some pollutants.

Toward that end, the U.S. Army Environmental Center (USAEC) has been testing the feasibility of using selected wetland plants to clean up explosives-contaminated groundwater at the Milan Army Ammunition Plant in Tennessee as an alternative to the labor-intensive, costly processes of granular activated carbon and advanced oxidation. These efforts were stimulated by tests undertaken by the EPA National Exposure Research Laboratory in Athens, Georgia, that identified a plant nitroreductase enzyme shown to degrade TNT, cyclonite (RDX), and high-melting explosive (HMX) in concert with other plant enzymes. Further testing identified similar nitroreductase activity in a wide variety of aquatic plants, which opens the door to a variety of potential applications for explosives residue cleanup utilizing constructed wetlands.

Another example of the increasing interest in the potential for plants to function as natural ‘‘remediators’’ of polluted soils and waters comes from the Great Plains–Rocky Mountain Hazardous Substances Research Center (HSRC), which confirmed that poplar trees (*Populus* spp.) can be utilized to prevent pesticides, herbicides, and fertilizers from contaminating surface and groundwater. As reported in EPA’s *Ground Water Currents* (U.S. EPA 1993c), poplars and other plant species are also being studied at Superfund sites for use in removing other organic contaminants and metals. A three-year-old poplar crop planted along a stream bank adjacent to a corn field by a University of Iowa research team reduced nitrate nitrogen levels in leachate from fertilized fields through uptake of soluble inorganic nitrogen and ammonium-nitrogen and their conversion into protein and nitrogen gas. In addition, the trees were shown to slow the migration of volatile organic chemicals and to transform atrazine into carbon dioxide.

These are just a few examples of the shift in focus during the past half century toward belated recognition of the incredibly varied physiology and chemistry associated with plants and their potential value as sources of natural assistance in pollution control, not to mention their ever-increasing importance as potential sources of new drugs.

PUBLIC ATTITUDES AND SUSTAINABILITY

The citizens of many communities are often the visionaries, and are ahead of most government officials in their interest in developing sustainable landscapes, innovative experiments, ecological art, and collaborative multidisciplinary efforts. It is somewhat understandable that government officials prefer dealing with projects with simple mandates rather than multiple functions, and with one set of consultants rather than a collaborative effort involving various disciplines. Government standardized, single-focus projects, which often, incidentally, present roadblocks to interdisciplinary teams and experimental designs, are often mundane projects that do little to advance human knowledge or to engage people’s emotions and intellect. Much of the impetus for more creative approaches to problems of infrastructure development, management of resources, and environmental preservation is coming from community groups and organizations.

Once again, it is only fair to point out that from a government administrator’s or regulator’s point of view, outsiders are not the ones who have to take the heat when an innovative project goes wrong. They *are*—which tends to reinforce the tendency for government agencies to support the most conservative approach to major infrastructure projects. This situation is changing, as the governmental entities that have taken the lead in sponsoring innovative solutions, from support of ecological art to constructed wetlands for stormwater renovation, have won awards and received publicity that makes the path easier for others to follow. Examples cited in later chapters of this book illustrate how some cities and other entities have taken the lead in supporting innovative multipurpose projects in a variety of venues that have created a positive image for constructed wetlands, along with a challenge to both professional designers and their clients involved in development projects around the country. A detailed description of many of these projects is presented in Chapters 9 and 10.