Why there are no better systems than constructed wetlands to treat sewage water: Advantages, Issues and Challenges

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ABSTRACT

Despite the demonstrated ability of subsurface flow constructed wetlands to treat effectively domestic and agricultural/industrial sewage wastewater, this ecotechnology has not been applied as widely as it deserves considering the great added value such systems offer. Some of the reasons are lack of awareness of this option, lack of experience and/or availability, especially in countries where the technology has not been previously developed. While having limitations, especially in their need for land, constructed wetlands are appropriate ecologically-based solutions, particularly for treating and reusing residential sewage, and especially for small, decentralized systems in remote or developing regions. Sewage treatment systems must be low-tech, low maintenance and minimal in their energy requirements to be affordable and easy to maintain in such applications, attributes which constructed wetland systems exemplify. Typical “package plant” or municipal sewage plant requires high capital investment, technical expertise and are energy-intensive to operate, while often a great nuisance for neighbours. Subsurface wetlands use little or no electricity and technology and require little technical supervision once installed. Previous studies of subsurface flow wetlands for sewage treatment have demonstrated their advantages in situations of small on-site sewage loading and in situations where avoidance of malodour and mosquito-breeding are important. A well-designed subsurface flow wetland can not only provide inexpensive and highly effective sewage treatment, but also great added value though the creation of additional green zone, biodiversity and productivity such a system enables. Constructed wetlands can also be conceived as buffer zones between human activity and natural green spaces. Sewage treatment can and should do far more than simply preventing pollution and the degradation of natural ecosystems occasioned by the incomplete treatment and discharge of wastewater. Wastewater treatment should also accomplish the return of nutrients and water to productive use. Nutrient recycling is just as central to the challenge of transforming human economic activities in Earth's vaster biospheric life support system to a sustainable basis.

As Wastewater Gardens systems have been developed around the world, it has become evident that the next step beyond sewage water treatment however is to come as close as possible to total productive use of water and nutrients – not simply removal of sewage water “pollutant/nutrients”. This has changed our conception from the old paradigm of “final disposal, e.g. leachdrains” to incorporating greywater recycle/irrigation where possible via subsoil irrigation of the treated effluents and designing robust systems with a plant diversity as wide as

possible and as productive as possible (fruit trees, medicinal plants, animal fodder, flowers, wood, … etc), depending of local need and wishes.
The interdisciplinary nature of the knowledge base behind constructed wetlands however – from ecology to engineering to botany/agronomy - however often makes the technology more difficult for specialized government and institutions to deal with ; in addition, like any ecological system, constructed wetlands are complex, living systems and unlike mechanical systems respond and evolve in response to local conditions and climate. Numerous parameters must be considered to ensure successful design and implementation as well as generalized sizing/treatment formulas. This paper will examine general issues and challenges illustrated by a few case studies from our work around the world.

Author Keywords: Wastewater Gardens, Sewage water treatment; Tratamiento de aguas residuales ; Ecotechnology; Ecotecnología ; Constructed wetlands; Humedales artificiales ; Subsurface flow ; Flujo subsuperficial ; Biodiversity ; Biodiversidad ; Recycle ; Wastewater reuse ; Reuso de aguas residuales ; Productive green zone ; Productividad vegetal; Buffer zone, Zona de tampón ecologíco ; Landscaping ; Paisajismo.

INTRODUCTION

The issue of sewage water treatment is today primordial in two regards: water pollution has far reaching consequences in terms of environmental and ecological health while in the majority of cases, depending on type of primary treatment used, sewage water can be used as a highly productive resource. As water in some communities is a valuable resource, treating sewage water as something dirty to disregard is proof of damaging ignorance which should no longer be allowed. The connection between "wastewater" by human activities and safe recycling into the overall water cycle has been made evident by the Biosphere 2 experiment, the materially-closed ecological system in Arizona which used the facility as a prototype for eventual space biospheric systems and as a laboratory for study of the global ecology, especially the harmonious interaction of appropriate technologies and natural systems [Nelson and Dempster, 1996; Allen et al, 2003; Nelson et al, 1993; Allen and Nelson, 1999]. To complete water and nutrient cycles within the facility required a simple yet effective wastewater treatment and recycling system. This was accomplished working with scientists from NASA Stennis Center [Wolverton, 1990] through constructed wetlands, using both floating and emergent (soil-rooted) plants. In a materially-closed system, there is only a finite quantity of materials. Biosphere 2 had an air-exchange (or leakrate) of under 10% of its atmosphere per year which for a human-built facility of some 200,000 cubic metres and a footprint of about 1.2 hectares is considered an remarkable engineering achievement. The Earth's biosphere is actually much more materially-closed and scientists know that the long-duration of its evolving biosphere is a reflection of the ability of its life systems to complete critical cycles. These are called the global biogeochemical cycles since at the scale of the Earth there are vast buffers (e.g. the atmosphere, oceans, geologic depths) and complex pathways between processes that are primarily life-driven and those that involve the Earth's geology, climate and chemical processes. But the essential point is the same – cycling or as we now term it "recycling" is essential to keep resources available for the maintenance and evolution of life on this planet. Biosphere 2 created an air-tight "mini-world", supporting eight people with their technical/research laboratories, habitat and agricultural/food production and a variety of natural ecosystems in a virtually air-tight environment for two years. Its constructed wetland, which for over two years successfully treated and recycled the wastewater from humans, domestic animals and laboratory/workshops, sent its remaining nutrients and freshwater back into supply for the system's intensive agriculture irrigation system. Vegetation from the constructed wetland increased plant biodiversity, provided additional habitat space and beauty. The plants of the constructed wetland were pruned to supply animal fodder for the domestic animals – whose solid waste was composted and whose wastewater returned to the constructed wetland. In such a small system, an approach to completely closing the loop between food production and sewage was possible. This research experience further inspired the development of high biodiversity "Wastewater Gardens" in cooperation with the University of Florida and the Planetary Coral Reef Foundation. In the years since initial research and applications along the Yucatan Peninsula in Mexico, the technology has evolved and been implemented in over ten countries to date. This mirrors the spread of more natural approaches to sewage treatment and water recycling/reuse which reflects growing concern about human health and environmental degradation caused by sewage pollution, and the recognition of the limited resource the Earth has of clean, potable water. The high economic and ecological costs of centralized sewage treatment – pump stations, high-tech treatment plants with machinery and use of chemicals, ending with "disposal" rather than reuse of the water is in contrast to the benefits which can be realized from intelligent design of small, decentralised and on-site treatment and reuse systems. We have now added to the original concept of Wastewater Gardens – subsurface flow constructed wetlands planted with high diversity and use of commercially valuable plants – the concept that total reuse of the water should be the objective. Treated water from the constructed wetland is used for subsoil irrigation of "ecoscapes" adapted to the landscape and climate, affording more uptake of remaining nutrients and reuse of the freshwater. These ecoscapes can use native and "bushtucker" plants and/or be used to provide fruits, timber, fibre, medicinals and landscape-enhancing vegetation. This is a way for the local community, the stake-holders, to shape the technology to their needs and desires. The paper and presentation will trace the evolution of our approach, with case studies and data from some of the international projects, illustrating both some of the innovative successes we have achieved, and the challenges of refining the design and adapting the technology to local economic, cultural and climatic conditions. Closing the loop in our global biosphere will be more difficult than it was in Biosphere 2, but the challenge is the same – water conservation and reuse are key elements for both human and biospheric health.

THE NUTRIENT AND WATER RECYCLING SYSTEMS OF BIOSPHERE 2

Figure 1 illustrates the major components and interconnections of the Biosphere 2 freshwater systems. The constructed wetlands were a crucial part of the treatment and recycle process. Two systems were designed – one to treat all the human residential wastewater and a second to treat urine/washdown water from the domestic animals and wastewater from workshops and laboratories inside the facility. Two separate wetland systems were created so that laboratory or mechanical workshop water could be isolated if necessary in case of chemical or oil/grease spills. This was not the case during the two-year closure experiment, and the two wetland subsystems were utilized interchangeably as required for maximizing hydraulic residence time. The system began with collection of wastewater and residence in anaerobic holding tanks where primary treatment and settlement of solids occurred. The system was designed for a daily loading of 1 m^3 (260 gallons). Around 750 m^3 of wastewater were treated over the course of the two year closure experiment, 1991-1993. The two constructed wetlands totaled 41 m^2 of surface area with emergent and floating plants and produced a total of 720 kg, dry weight, of emergent vegetation and 493 kg, dry weight, of floating vegetation during the two-year experiment (Figure 2). Analysis for BOD indicated reduction was >75% with hydraulic retention times of around four days in the holding tanks and three days in the wetland treatment system. Because the eight person crew carried no infectious diseases prior to the two year closure experiment, there was no need to use a high intensity UV light system which was available as a method of disinfection of the effluent before it was sent to irrigation water tanks for the agricultural crops.

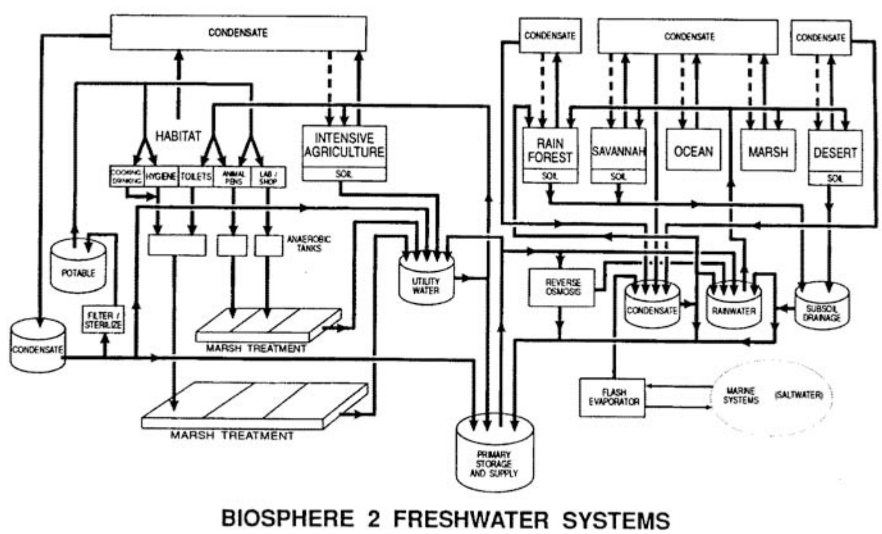


Figure 1. Water systems diagram for the Biosphere 2 closed ecological system facility, Oracle, Arizona. The "marsh treatment" were two constructed wetlands designed to treat and recycle wastewater from all sources inside – gray and blackwater from the eight people living inside; wastewater from the domestic animals; and water from analytic and medical laboratories. Remaining nutrients and treated water were sent to irrigation supply for the Biosphere 2 agriculture system.

The wetland system was housed in several fiberglass tanks and submersible pumps maintained water recirculation between tanks. Loading to the system was on a batch basis after the primary settling tanks became full. Fourteen plant species composed the primary autotrophic level in the wetland system (Table 1). The constructed wetland system supported floating (aquatic) and emergent (rooted) wetland species (Figure 2). The aquatic plants colonized open-water channels and the emergents utilized the higher soil areas in the wetland. The system served as habitat for insects (e.g. lady bugs) and animals (such as the Colorado cane toad) within the Biosphere 2 agricultural biome. The system operated with few problems, but technical changes after the two-year experiment were instituted to make water sampling easier, to prevent overfilling of tanks and lower labor requirements. The constructed wetlands increased biodiversity within the facility and helped complete water and nutrient cycles.

Scientific Name	**Common Name**
Azolla caroliniana	Mosquito fern
Canna edulis	Canna
Canna flacida	Golden canna
Canna indica	Indian shot
Eichornia crassipes	Water hyacinth
Ipomea aquatica	Water spinach
Lemna minor	Duckweed
Pistia stratoites	Water lettuce
Phragmites australis	Common reed
Sagittaria falcata	Wapato
Sagittaria montevidensis	Giant arrowhead
Scirpus californicus	Bullrush
Spirodela polyrhiza	Duckweed
Wolffia sp.	Water meal

Table 1. Vascular plants in the Biosphere 2 wetland wastewater recycling system during the two year closure experiment, 1991-1993

(b)

(a)

(c)

Figure 2. (a) one of Biosphere 2's constructed wetlands shortly after planting. Burlap bags hold soil for emergent vegetation next to free surface areas for floating (aquatic) wetland plants. (b) the constructed wetland during the two year closure. (c) Harvesting wetland plants for fodder for domestic animals.

APPROPRIATE WASTEWATER TREATMENT APPROACH FOR REMOTE COMMUNITIES AND DEVELOPING COUNTRIES

Nutrient recycling is just as central to the challenge of transforming human economic activities in Earth's vaster biospheric life support system to a sustainable basis. Sewage treatment should do far more than simply preventing pollution and the degradation of natural ecosystems occasioned by the incomplete treatment and discharge of wastewater. Wastewater treatment should also accomplish the return of nutrients and water to productive use. An important development of the past few decades has been the use of natural and constructed wetlands for the treatment of domestic sewage and industrial wastewater and the recognition of the need for water conservation and greywater recycle/irrigation.

After the Biosphere 2 experience, the lead author (MN) worked with the Planetary Coral Reef Foundation (a division of the Biosphere Foundation) and H.T. Odum and Center for Wetlands at the University of Florida to further the development of appropriate ecologically-based solutions for treating and reusing residential sewage especially for small, decentralized systems in remote or developing regions. Sewage treatment systems must be low-tech, low maintenance and minimal in their energy requirements to be affordable and easy to maintain in such applications, attributes which constructed wetland systems exemplify. Natural and constructed wetlands rely on solar insolation as a main driving energy, and warmer climates improve treatment rates (Kadlec and Knight, 1996). Therefore, wetland treatment systems may be expected to operate more effectively in warm, high sunlight Mediterranean, arid and tropical regions. In addition, wastewater interface ecosystems may benefit from the higher species diversity found in such areas since diversity at the biotic and metabolic level increases the buffering capacity of ecosystems (Mitsch and Jorgensen, 1991). Allowing self-organization of plant, animal and microbial biota to develop cooperative mechanisms may develop better adapted ecosystems to handle pollution and toxicity (Odum, 1991).

Previous studies of subsurface flow wetlands for sewage treatment have demonstrated their advantages in situations of small on-site sewage loading, in areas where land is scarce, and in situations where avoidance of malodour and mosquito-breeding are important. A well-designed subsurface flow wetland also can provide inexpensive but highly effective sewage treatment. As is the case in the U.S. and Europe where this approach is rapidly spreading, the advantages of constructed wetlands are that because they rely on more natural methods, they are less expensive to build and operate than conventional sewage treatment plants. They can also produce a standard of treatment comparable to advanced wastewater treatment (Reed et al, 1995). Typical “package plant” or municipal sewage plant requires high capital investment, technical expertise and are energy-intensive to operate. Subsurface wetlands use little or no electricity and technology and require little technical supervision once installed. Although more expensive per unit area than free-surface wetlands, because of the cost of impermeable liner and gravel media, they have more intense treatment action, reducing required area significantly (Green and Upton, 1992; Steiner et al, 1992; Cooper, 1992).

INITIAL APPLICATIONS IN THE YUCATAN PENINSULA, SOUTHERN MEXICO

Commencing in 1996, several dozen Wastewater Garden, subsurface flow constructed wetlands were installed for houses, condominiums, restaurants and small hotels south of Cancun, Mexico in the Yucatan Peninsula coastal region. This is an area characterized by highly karstic (limestone) soils and as such are highly permeable to the flow of wastewater which pollutes water tables found quite close to the ground surface and adversely affects the coral reef adjacent to the coastline. Experiments were commenced with use of a high biodiversity of plants, both native and decorative/valuable ones already in the region. Most of these systems were completely gravity-flow but for some installations, to avoid jack-hammering through hard limestone, the constructed wetlands were designed as raised garden boxes and submersible pumps raised effluent from the septic tanks to the systems. Table 2 presents the water quality data over a two year period from the first two Wastewater Gardens (Nelson, 1998a, 1998b). Discharge water from the systems was sent to subsurface leachdrains and in one case studied, to a nearby mangrove area whose self-created high-organic peat soils offered a promising final biofilter.

Figure 3. Photo gallery of selected Mexico Wastewater Garden projects (a) Xpu-Ha Ecopark restaurant system creates attractive landscape around the facility (b) ecological field station centre, Akumal, Mexico (c) garden near entry way to private house is an ecological wastewater treatment system as well (d) Wastewater Garden unit in front parking lot of Italian resort and restaurant, Tulum, Mexico

Parameter	In (Septic Tank) mg/l	Out (discharge WWG) mg/l	Removal %	Loading Kg/ha/d
BOD (Biochemical oxygen demand)	145	17.6	87.9	32.1
Total Phosphorus	8.05	1.9	76.4	1.7
Total Nitrogen	47.6	10.0	79	10.3
Total Suspended Solids	69.9	38.9	44.4	
Coliform bacteria	4.9×10^6	2.2×10^3	99.8%	

Table 2. Removal efficiency and loading of Wastewater Garden subsurface flow systems Studied at two initial locations in Mexico (1996-1998) (Nelson, 1998a, Nelson, 1998b). The coliform bacteria reduction was without using chlorine or other disinfectants.

In the initial years of operation, these systems returned very good water quality results and maintained high levels of biodiversity. However, with the passage of time, many systems suffered from poor maintenance such that taller vegetation was not pruned back and was allowed to shade out understory plants, resulting in a loss of effective wetland biomass and diversity. It is also suspected that system design, with short distances to discharge pipes may have resulted in short-circuiting. Subsequent testing showed COD reduction had fallen to 65-70% and nutrient reductions had declined as well.

These lessons have led to several design thinking evolution:

1 - The realization that the goal should be as close to total productive use of water and nutrients – not simply the level of removal in the constructed wetland, has changed our conception from the old paradigm of “final disposal, e.g. leachdrains” to incorporating greywater recycle/irrigation where possible and designing a robust subsoil irrigation of the treated effluent from the Wastewater Gardens units;

2 - Length to width ratio needs to be at least 4:1 to lessen chance of short-circuiting and use of internal baffles in the wetlands when possible;

3 - Maintenance manuals and training were upgraded to emphasize the need for attention to the systems, especially filters in septic tanks, pruning for maintaining good numbers and diversity of vegetation, especially that of deeper-rooted wetland plants, removal of any organic matter which begins to build up on the gravel surface and attention to primary treatment system performance;

4 - For situations which demand higher initial treatment performance, use of vertical flow design which results in better aeration and thus reduction of N and BOD. These systems generally require use of dosing siphons or pumps to ensure batch-loading and are thus more technically-demanding and reliant on electricity but are best adapted in some situations.

In the years since, Wastewater Gardens International has operated both through doing design consultation and implementation world-wide on a project basis, and has worked with regional representatives to carry forth applications in selected regions. These include: Indonesia, Poland, Spain/Portugal, North Africa, and in the Kimberley region of West Australia.

WORLDWIDE APPLICATION OF WASTEWATER GARDENS

INDONESIA

Wastewater Gardens® came to Indonesia in 1999, when Mark Nelson began work with Emerald Starr, a designer/builder on the resort island of Bali to fill a gap in available technologies on the island by providing an effective wastewater treatment solution for resorts, hotels, businesses and communities at a price affordable in terms of the local economy and manageable in terms of local engineering and construction expertise. Water-related issues in Indonesia concern both supply and conservation of potable water and proper treatment of wastewater. Since the onset of mass tourism, water use on the island has increased dramatically. The UNDP projects that on current rates of use and existing policies for the expansion of tourist facilities, water supply for Bali would be in deficit within a decade, and demand would reach four times potential supply by the middle of the next century (Warren, 2000). Also the vast majority of Bali's and Indonesia's wastewater goes completely untreated, fouling rivers, groundwater and adding to environmental damage. The consequences for human health are also enormous. Starr and Nelson provided a living example of how the Balinese tourism industry might re-use and re-cycle the huge volumes of water it requires by implementing several WWG at the Sacred Mountain Resort he helped design and build in Sideman, Bali (Figure 3).

Figure 4. Photo gallery of selected Wastewater Garden projects in Indonesia. (a) restaurant at Sacred Mt. Sanctuary, Sideman, Bali (b) Sunrise School, Legian/Kuta, Bali where 20 m^2 WWG for toilets serves 70 students and staff (c) private residence courtyard WWG (d) diving resort, Menado, Sulawesi (e) 1/3 WWG unit for Bapedalda governmental offices.

After the success of this project, IDEP Foundation, a local environmental education organization working to train Indonesians in environmentally friendly solutions, set up a Wastewater Garden division, working with Nelson and the Planetary Coral Reef Foundation (U.S.), to implement constructed wetlands. The early years of this partnership saw 15 more WWG installed at hotels and resorts across Indonesia including one at the Tirtagangga Water Palace, an icon of Balinese culture funded by the Seacology Foundation and Livingry Foundation. Several systems were also implemented at several dive shops and resorts near Bunaken Marine Park, Menado, Sulawesi, a national marine reserve (Figure 4). Also of note was a village bamboo treatment centre using mangroves in the Wastewater Garden as an educational demonstration of the importance of mangrove conservation (working with the Mangrove Action Project) in a fishing/farming village near Menado. These first projects began the process of socializing the technology into the Indonesian and Balinese contexts. During this time Mark Nelson presented the technology to various Balinese institutions including BAPEDALDA, the provincial wing of the Indonesian government's environmental regulation body, and to Udayana University, Bali's institute of higher learning. The reception from these institutions has been extremely promising and BAPEDALDA has since branded the technology with their official support as well as contracting three WWG units for government buildings (Figure 4). Negotiations are now under way to determine the feasibility of standardizing and regulating the WWG technology for required implementation on larger scale building projects.

In recent years, the IDEP Foundation has continued to design WWG systems for commercial interests while focusing on the development of the technology in the wider Indonesian context (outside the tourism industry). Efforts towards this goal include training of local designers/builders and research into alternative materials and applications for the technology. Notably, the system is being implemented in post-tsunami reconstruction efforts in Aceh, Sumatra, Indonesia. The Acehnese context is a current focus of Yayasan IDEP's training program.

The Indonesian Context: The tropical archipelago of Indonesia provides an ideal context for the implementation of the WWG technology in terms of climate, available materials, and the overwhelming need for wastewater solutions. Year round sun and high average temperatures provide a "natural greenhouse" to support a vast array of food crop, craft, medicinal and ornamental plant species, thus allowing WWG to be designed for aesthetics and productivity as well as utility. Some of these native plants such as the ijuk palm tree fiber have also provided materials for replacement of manufactured septic tank filters and for geotextile covering of subsoil irrigation lines.

Materials : One of the primary advantages of the WWG technology in rural situations is its adaptability to locally available materials. While Indonesia is comparatively lacking in manufactured and processed materials for waste management systems, the vast biodiversity of the archipelago has provided several practical solutions. In their simplest form WWG consist of an impermeable layer, plant media, filter materials, and piping. The investigation of alternative, local materials is continuing and offers a way to lower the costs to make such systems more affordable at the local economy level (Table 3).

	Manufactured solutions	**vs. Local solutions**
Impermeable Liner	1) Steel re-inforced concrete 2) Geomembrane (butyl or other)	1) Bamboo re-inforced ferro-cement 2) Compacted clay (when available) 3) Gley
Media	Crushed gravel (delivered)	1) River rock (on-site and if harmless to local ecosystem) 2) Crushed Limestone (on-site) 3) Pumice / Volcanic rock (on-site)
Filter	Commercial filters	Ijuk and other natural fibers

Table 3. Possible lower-cost and local materials for use in construction of Wastewater Gardens in developing countries/remote areas.

Water testing

Use of local water testing facilities on Bali have been a challenge to the research and reporting aspects of IDEP's work with WWG. Results received to date are promising but leave some question as to the accuracy of the methods used. On the positive side, these tests indicate that nutrient removal is of acceptable standards: 75% removal of total N and 57% removal of total P, TSS reduction of 69% to 0 21 mg/l, but COD reduction is 64% and BOD just 40% if the tests are accurate.

Averages

	NO^3	NH^3	PO^4	BOD	COD	TSS
INPUT	3.6599	19.1525	21.204	112.91	641.2	76
OUTPUT	2.462	2.93875	8.8614	68.77	230.24	21
% Reduction	**28.95**	**80.89**	**57.42**	**39.01**	**61.11**	**68.91**

Project Examples

Villa Sawah
Area= 16m^2
Depth= 80 cm

	NO^3	NH^3	PO^4	BOD	COD	TSS
INPUT	5.528	8.5	18.763	146	540	115
OUTPUT	3.518	2.2	9.2683	88.62	312	28
% Reduction	36.4	74.1	50.6	39.3	42.2	75.7

Robert Kusnanto
Area = 11.5m^2
Depth = 75 cm

INPUT	1.7918	29.805	23.645	79.82	742.4	37
OUTPUT	1.406	3.6775	8.4545	48.92	148.48	14
% Reduction	21.5	87.7	64.2	38.7	80.0	62.2

Other applications solving water pollution problems: Continuing international research in phyto-remediation suggests that the wastewater garden technology could be applied as an antidote to other sources of wastewater pollution. Yayasan IDEP is currently exploring techniques for using Chinese Brake fern to uptake arsenic from polluted well water in Aceh, Sumatra and purifying irrigation water of residual heavy metals from heavy use of pesticides and chemical fertilizers in wet rice agriculture. Other industries such as jewelry and cloth-dying may also be a good application for constructed wetlands and bio-remediation.

POLAND

In Poland, wastewater treatment is a very serious problem. According to statistical data, only 53.1% of the population is serviced by wastewater treatment plants. On one hand, water is supplied to 91.5% of population in cities and 30% of population in rural areas. On the other hand, only 83% and 9.9% of these populations respectively is serviced by wastewater treatment plants.

The worst situation is in the rural, sparsely built-up areas. Small, isolated communities have difficulties in building and maintaining highly technical wastewater treatment systems. Very often, traditional treatment plants are not maintained because of financial problems or the treatment plants are not operated professionally. As a consequence, wastewater remains untreated or is cleaned insufficiently. These problems become especially important in areas with important natural resources such as conservation areas, national parks and Biosphere Reserves.

The first Wastewater Gardens units have been installed in the Carpathian Mountains in the year 2000 in cooperation with local NGO called Carpathian Heritage Society. System built for Research Station of the Jagiellonian University in Krempna in the Magurski National Park purifies wastewater from 20 people. It is composed of 24 m^2 of gravel planted with local species. Treated wastewater feeds adjoining orchard. Since year 2002, 12 systems Wastewater Gardens have been built in Poland – mostly for private houses or businesses.

The well designed and constructed Wastewater Gardens® system complies with Polish environmental regulations, European standards, United States Environmental Protection Agency (EPA), and German ATV. It is confirmed by results from the pilot Wastewater Garden in Krempna (Table 4). That discharge water goes out to subsurface irrigation of a fruit orchard.

Parameter	Influent concentration	Effluent concentration	Percent reduction	Limit value*
BOD5	55.0 mg O2/l	11.0 mg O2/l	80%	40 mg O2/l
COD	88.0 mg O2/l	32.0 mg O2/l	64%	150 mg O2/l
SS	74.5 mg/l	49.5 mg/l	34%	50 mg/l
Total N	73.7 mg N/l	24.6 mg N/l	67%	30 mg N/l
Total P	7.2 mg P/l	2.0 mg P/l	72%	5 mg P/l

Table 4. Results from the pilot Wastewater Gardens system in Krempna, Poland in the Magurski National Park. * According to Polish environmental regulations.

(a) (b) (c)

Figure 5. Plants in the Wastewater Gardens at Magurski National Park, Krempna, Poland serving the research station of Jagiellonian University. The systems were financed with the support of the Sendzimir Foundation and WWF.

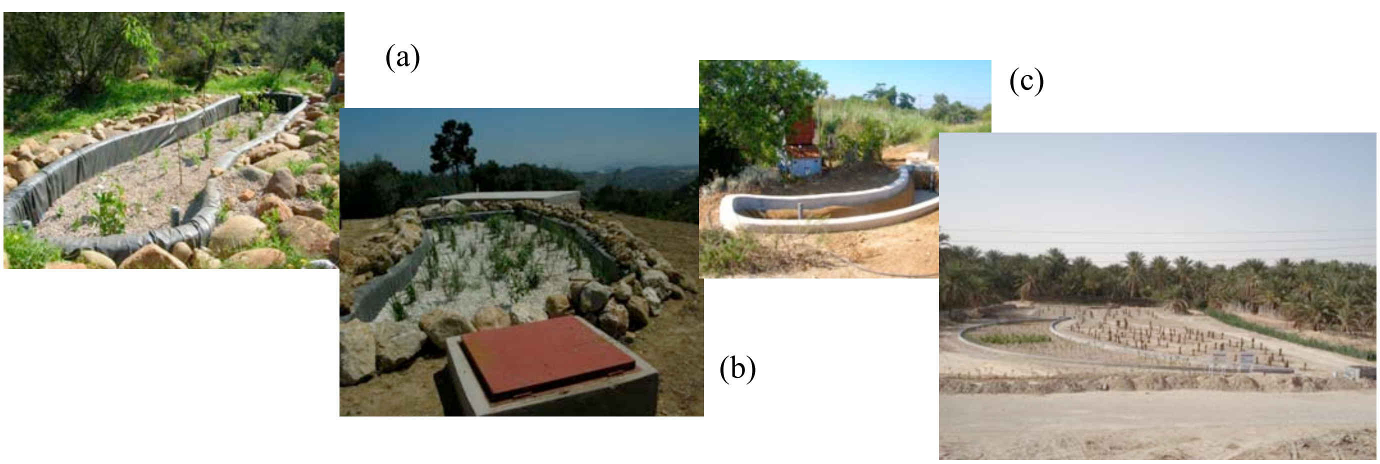
Beside practical and tangible activities like building the wastewater treatments system, there is an ongoing project for the promotion of Wastewater Gardens targeted to increase knowledge about constructed wetlands and to build confidence in such natural approaches to wastewater treatment solutions. This project has been run in cooperation with the Institute of Environmental Sciences of the Jagiellonian University in Krakow that was given the status of the European Center of Excellence (project IBAES # EVK2-CT-2002-80009), with the support from European Union and several private foundations. The main objective of the project was to raise awareness of constructed wetlands as an alternative to industrial wastewater treatment among decision-makers and general public. Basing on the feedback information that has been received so far, it can be stated that public interest concerning application of Wastewater Gardens increases as a result of the accomplished projects' tasks. To raise awareness of constructed wetlands over 40 meetings with local decision-makers and general public have been arranged, accompanied by informational materials focused on highlighting benefits from constructed wetlands.

SOUTHERN EUROPE AND NORTH AFRICA

Working through a new Division of Wastewater Gardens International, we have chosen to be based in an area where desertification and water are of essential concern. Approached to implement projects for homes, hotels and urbanisation development projects, we are also contacted sometimes by small municipalities, as complementary treatment to existing or planned sewage treatment facilities. As of 2007 only a handfull of units however have been built for private homes and hotels in Spain and Portugal (Figure 6) while an entire building project for a new urbanisation in Portugal of 400 people at the edge of a natural sensitive zone has been recently approved based on the WWG study and proposal. We recently returned from Algeria where we were mandated by the Algerian Ministry of Water Resources to implement a pilot unit for 100-150 persons, to serve as a base for future constructed wetlands throughout the country (Figure 6). Implemented and planted WWG units are too recent however to present any water testing results in this paper.

At the difference of areas such as Mexico or Indonesia, cost can represent a problem in areas such as European countries where manpower and material are often significantly higher: constructed wetlands often come out as twice or three time as expensive as a compact 3 chamber "conventional" water treatment system for instance. Our experience is that unless an additional green zone at no extra water expense is desirable, constructed wetlands don't come out as economically viable as a short term initial investment for people who only care to comply to the legislation in place: one must count between 400€ and 1500€ /person for the design and construction, primary treatment and drainage included (often omitted in other types of systems), depending if the project is close to the WWG team or far away, depending on whether landscaping is included or not, maturity of plants that are planted, nature of the soil to be excavated, …etc. From our experience, it is only in cases where water is a critical issue in terms of shortage and where there is a great desire to create extra vegetation zones that the step to implementation takes place.

Challenges: while the situation is rapidly evolving since the beginning of our presence in southern Europe, about 50% of our work in Spain for instance, has been about informing and educating the public as well as municipalities, which often don't have the knowledge of the efficiency and functioning of constructed wetlands; a lot of misconceptions about these systems have to be dealt with, for instance the erroneous perception that a system that "only" holds gravel and plants cannot possibly be as effective as a mechanical or chemical product based plant and is a romantic and "hippy" kind of system. It is interesting to note the difference of perceptions in regards to the value of water and thus the investment that may accompany it to give it a longer and useful cycle of life. In Africa for instance, where we are in contact with various institutions, demands for such systems come from municipalities for which a WWG treatment unit also enables to grow valuable crops, such as fast growing trees, fodder for animals, fibres, medicinal plants and valuable native plant species in the constructed wetland units, and then also in the drain/subsurface irrigation area with fruit trees, flowers and various other valuable crops. In Europe however, the value of such a system is rather perceived for its decorative potential when there is a situation of water stress / lack of availability in areas where people are dependent on a well and wish to add green zones to their land. In these cases, we are often asked to work with landscape designers, which also significantly reduces cost to the client.



(d)

Figure 6. Photo gallery of selected Wastewater Garden projects in southern Europe and Africa. (a) Private residence on the Malaga coast, Spain, recently planted with 14 species (b) Private residence on the Marbella coast, Spain, recently planted with 11 species, with the leachdrain area used for complementary irrigation of 15 frutal trees (c) Private residence in Portugal not yet planted (d) Pilot 400 m^2 WWG unit in the shape of a crescent moon, Temacine, Algeria, recently planted with 23 species in the constructed wetlands, the majority of which are for productive use (weaving fiber, medicinal plants, fruit trees, essential oils, cut flowers…) and leachdrain area used as complementary subsurface irrigation for 138 fruit trees, 17 species (on the photo, protected by palm leaves).

WEST AUSTRALIA

In 2000, the West Australian Department of Health approved the commencement of some pilot projects using the Wastewater Garden approach in the Kimberley of northwest Australia, since remote towns and indigenous communities need practical, decentralized solutions to sewage treatment and reuse. Working with Birdwood Downs Company which has been implementing environmental upgrade and integration of sustainable approaches in the region (Allen et al, 1984; Nelson, 1985), several projects have been implemented.

Birdwood Downs homestead kitchen/dining room/library/toilet and shower: an 8 m^2 Wastewater Garden was sunk 0.5m into the ground to permit gravity-flow from an existing septic tank. The system handles half the wastewater from a resident and tourist population from 5-12. The remaining wastewater is used for subsoil irrigation of a banana and fruit tree patch near the ablution block. The Wastewater Garden system has operated without problem for over 6 years and was monitored for water quality improvement (Table 5). The garden supports heliconia (Bird of Paradise), canna lilies, pandanus palm, coconut palm, plantain, 2 types of elephant ear, papyrus and oleander (Figure 7). Treated effluent irrigates other trees in the back of the homestead

Figure 7. Wastewater Garden at Birdwood Downs' homestead offers an inviting perch area for peacocks on the paperbark fencing.

Parameter	BOD-5 (Biochemical Oxygen Demand) mg/l	Total Suspended Solids (TSS) mg/l	Total Nitrogen mg/l	Total Phosphorus mg/l	Total Coliforms Cfu/100 ml
Average in Septic Tank	241	338	52.5	10.3	6,285,000
Average Wastewater Garden discharge	12	16.5	27	7.3	116,000
Percent Reduction	95%	95%	48%	30%	98.2%

Table 5. Summary of water quality results from Wastewater Garden system at Birdwood Downs homestead, Derby, West Australia. Analyses were conducted at MPL Laboratories, Perth, an accredited testing facility. If evapotranspiration averages 20% in above system, total reduction of BOD is 96%, reduction of TSS is 96%, reduction of N is 59%, reduction of P is 43%, and reduction in coliform bacteria is 99%.

Emu Creek (Gulgagulganeng) community, Kununurra

Several of the houses at Emu Creek community are on very low-lying soils, adjacent to natural wetlands, and since the community was moved to this location, there have been problems with failure of leachdrains, sewage on the ground and house plumbing backing up. For a small community (30-50 residents) centralised solutions, such as sewage lagoons, are very expensive and would require daily power and technical maintenance. The solution implemented with community participation in the planning was three Wastewater Garden systems, constructed in June 2002, to serve the various houses on the community. To minimize dependence on electricity and machinery, the two systems serving the lower three houses were sunk into the ground (in one case reaching groundwater at 0.7m below surface in June) so that septic tanks can discharge through pipelines by gravity-flow into the Wastewater Gardens. For these two systems, dual submersible pumps were installed in the control box after the WWG, so that during the wet season if the ground gets saturated, the gravity-flow leachdrain can be turned on, and the pumps will discharge subsoil to an area of higher elevation sandy soils which never get saturated. The third system serves a house on the higher elevation side of the community and only required a gravity-flow system.


(a)


(b)

Figure 8. One of three Wastewater Gardens at Emu Creek community, Kununurra, West Australia, with areas of 48 m^2, $30m^2$ and $24m^2$ treat the wastewater of the entire community. They have solved long-term problems with exposed sewage and failure of house plumbing due to high groundwater during the wet season. Combined WWG that serves two lowest houses (a). Control box covers were painted by community residents to increase stakeholder participation, here painted by Ned Johns.

The community was involved in design, layout and choice of plants; and several community artists painted dreamtime paintings on the control box covers to increase "ownership". But there has been very little motivation shown by the community, which is mostly "pensioner" and marked by periods of social instability, to maintain the Wastewater Gardens, despite the increase in beauty and greenery the systems continue to produce (Figure 8). The systems were fenced to prevent vandalism and children throwing rocks which cover the geomembrane liner. However, the systems were implemented at a fraction of the cost of a centralised lagoon system, and continue to operate despite very sporadic maintenance by local support agencies and workers in the CDEP program. Two years of water quality tests (Table 6) show relatively high levels of treatment are being achieved.

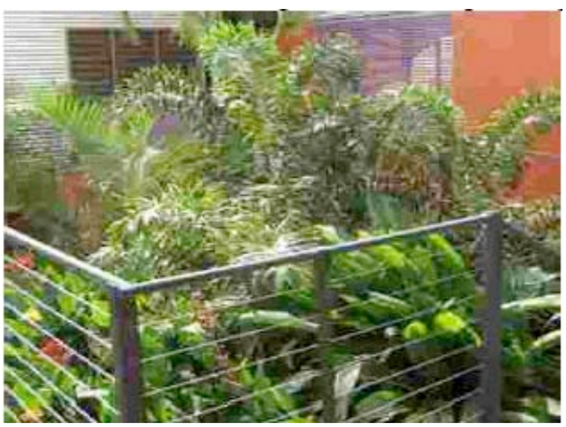
Parameter	BOD-5 (Biochemical Oxygen Demand) mg/l	TSS (Total Suspended Solids) mg/l	Total Nitrogen mg/l	Total Phosphorus mg/l
Average in Septic Tank	214	99	228	18
Average WWG discharge	23	10	66	7.8
Percent Reduction	89%	90%	73%	58%

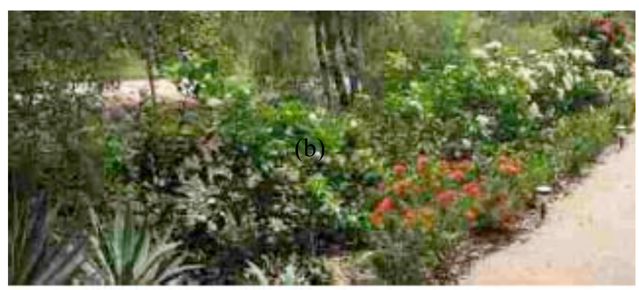
Table 6. Summary of water quality results at Wastewater Gardens at Emu Creek community, Kununurra.
Tests performed at MPL Laboratories, Perth, an accredited testing facility. If evapotranspiration is 20% for above system, then wetland reduction of BOD is 91%, reduction of TSS is 92%, reduction of nitrogen is 77% and reduction of P is 65%. Distance to laboratory prevented measurement of coliform bacteria.

Coco-Eco Bed and Breakfast, Coconut Well, Broome

The Coco-Eco B&B, Coconut Well, Broome is a ecologically-designed facility run on solar electric power which wanted to set a high standard for treatment and recycle of wastewater by using them to create lush, tropical gardens. Their 16m^2 Wastewater Garden is fit into the courtyard center of the facility and remaining nutrients are used in their subsoil irrigation leachdrain area to support additional decorative flowering shrubs and productive crops like banana (Figure 9). This enables them to protect fragile groundwater sources in the coastal area and create landscaping from wastewater while maintaining low water usage. Built in February, 2004, the facility was awarded the 2005 Laminex Group Single Residential Award from the Royal Architectural Institute of Australia in recognition of its ecological design and features.

(a)





(b)

Figure 9. (a) Wastewater Garden at Coco-Eco B&B, Coconut Well, Broome in courtyard between family house and guest rooms. (b) Flowering plants in the subsoil irrigation (leachdrain) area receiving treated effluent from the constructed wetland.

Joy Springs (Eight Mile) community, Fitzroy Crossing

At the Joy Springs (Eight Mile) community near Fitzroy Crossing, West Australia four of the houses on the low-elevation side experience leachdrain failure and plumbing backup during wet seasons when soils were flooded. As a solution, the houses were retrofitted in June/July 2004 with individual 12m^2 Wastewater Gardens and gravity leachdrains/inverted leachdrains. The latter were roughly $80m^2$ and built up 0.5m above ground levels with permeable local soils. Submersible pumps in the WWG control boxes can be activated to pump treated wastewater to subsoil perforated pipes in the inverted leachdrains for wet season operation of the system. The inverted leachdrains were planted with a mix of native trees and shrubs (especially valuable bush-tucker and medicinal plants) and the area is outfitted with a drip irrigation reticulation system on automated timer to provide irrigation for these backyard gardens in-between periods of wastewater application. The wastewater not only provides irrigation but also additional fertilizer because of the nitrogen and phosphorus in the treated water. A fifth house experiencing failure of an old leachdrain was fitted with a simple gravity-flow Wastewater Garden. Building on the experience from Emu Creek, we installed 1m high wooden bollard and post fencing with wire mesh as a more attractive solution for the exclusion of young children, dogs and grazing animals (Figure 10).

(c)

(a) (b)

Figure 10. Wastewater Gardens at Joy Springs (Eight Mile) Community, Fitzroy Crossing, West Australia include gravity-flow and inverted leachdrains for wet season operation. (a) The Wastewater Gardens are long and narrow, 1m x 12m, to fit into old leachdrains which were dynamited through hard underlying rock. (b) The inverted leachdrains were planted with a variety of native and decorative/useful plants and is watered by treated effluent during wet periods of the year and has a reticulated drip irrigation system as well. (c) both Wastewater Garden and inverted leachdrains are fenced with low wooden post and rail and mesh to exclude children, dogs and grazing animals.

OTHER COUNTRIES: THE BAHAMAS, PUERTO RICO, BELIZE, THE PHILIPPINES, FRANCE, U. S.

Since the year 2000, Wastewater Garden projects have been realized in a number of other countries including:

The Bahamas: a 2-cell, 80 m^2 system followed by subsoil irrigation was implemented at the Cape Eleuthera Island School, a school which focuses on environmental and science hands-on education. The system serves all the school and residential buildings and is a feature in the centre of their campus (Figure 11).

Puerto Rico: a 52 m^2 WWG serves all the grey and blackwater at the homestead buildings of the Las Casas de la Selva rainforest enrichment and forestry project near Patillas, Puerto Rico. The Department of Natural Resources funded the project as a demonstration ecological approach to sewage recycling and to protect mountain streams which feed water reservoirs for local populations (Figure 11). Water quality testing showed over 90% reductions of BOD, TSS and total N, total P reduced by 83% and a 99.9% reduction in coliform bacteria.

Belize: the Kanatik Reef and Jungle Resort installed two Wastewater Gardens to treat their restaurant, laundry and guest rooms, one of 200 m^2 and the other 120 m^2 to handle a total of 90-100 guests and staff.

France: a Wastewater Garden was installed at the Les Marronniers conference centre and ecological farm near Aix-en-Provence which treats all the conference centre kitchen and residential sewage.

The Philippines: Wastewater Garden systems were installed at the Children's Village project of the ABS-CBN foundation outside of Manila.

Figure 11: (a) Cape Eleuthera Island School, the Bahamas where a 2-cell 80 m^2 system serves the entire school and residential buildings; (b) picking flowers in the Las Casas de la Selva, sustainable rainforest project homestead WWG of 52 m^2, near Patillas, Puerto Rico; (c) Synergia Ranch conference centre, Santa Fe, New Mexico at 1500 m elevation in a cold high semi-desert environment where winter low temperatures can be below -10 to -20 deg C. (d) One of Wastewater Garden units at the Kanatik Reef and Jungle Resort, Belize.

CONCLUSIONS

The world is experiencing increasingly the importance and scarcity of our sources of fresh, clean water – and the necessity to improve human health and protection of our environment, both of which are threatened by contamination by human wastewater. In this context, new approaches which can replace or augment centralized high-tech wastewater treatment are crucial. Those in developing countries and/or in remote and small communities can neither afford the considerable infrastructure and machinery upkeep/maintenance requirements of centralized sewage treatment, nor will they benefit as much as by intelligent on-site, decentralised systems. The advent of a class of more ecologically-based approaches, such as using wastewater for greening, either through constructed wetlands and/or greywater recycle/irrigation creating locally-adapted "ecoscapes" offers some new and important alternatives which are be part of the solution to the looming 21st century water crisis of desertification prone areas in the world.

It is time that we put into practice the new understanding that "wastewater" is a misnomer, albeit sadly descriptive of what is normally done. Treating this resource as a sustainable part of the human economy will both save our potable water from overuse, and can lead to effective, natural methods of both hygienic treatment and reuse of this nutrient-enriched water supply to sustain and/or create vegetation zones. We can neither afford to throw this wastewater away, despoiling our groundwater and coastal water; nor to spend unnecessary technology and expense for simply "neutralizing" its pathogenic potential. "Closing the loop" in our global biosphere will be more difficult than it was in Biosphere 2, that is, returning nutrients in human wastewater to the farms where our food originates. But the challenge is the same – in our planetary biosphere, our ultimate life support system, water conservation and wastewater reuse are key elements for both human and biospheric health.

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