Value-adding through creation of high diversity gardens and ecoscapes in subsurface flow constructed wetlands: Case studies in Algeria and Australia of Wastewater Gardens® systems

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Abstract Two case studies are presented of recent applications of Wastewater Gardens (WWG) - for an Aboriginal community in northwest Australia and in southern Algeria. WWG uses high-diversity of plants in the subsurface flow wetland and in the final subsoil irrigation to value-add through water conservation, prevention of pollution of groundwater and by growing beautiful and when possible valuable plants suited to the climate. Treatment typically averages 90+% reduction of BOD and TSS, 98+% reduction in coliform bacteria and substantial productive uptake of nitrogen and phosphorus. WWG technology was originally developed from the necessity in Biosphere 2 to fully recover and recycle the water and nutrients in wastewater to complete the closed ecological system's water and nutrient cycles. In Australia, for Aboriginal communities, the greening achieved by using constructed wetlands has important health benefits in the community and treated water is used to subsurface irrigate desirable and harvestable native plants. In southern Algeria, vegetation is not only rare but many areas suffer from an increase in salinity because of extensive date plantations using deep fossil water in conditions of very high rates of evaporation. While untreated sewage adds to a worsening water situation and a general health degradation of existing water sources, using constructed wetlands is a proven method to both treat sewage and make it productive. Other values of the approach are that it reduces the use of potable water. Inexpensive wastewater treatment is important to protect potable water from contamination. In remote locations with a shortage of skilled technicians and uncertain electrical supply, systems need to be as easy to maintain as possible. Therefore Wastewater Gardens systems are designed using only gravity-flow water whenever possible. This also makes the systems competitive in price with more conventional sewage treatment facilities, in addition to their numerous value-added features.
Keywords: biodiversity, constructed wetlands, wastewater treatment, Wastewater Gardens, water recycle, water reuse, water conservation

INTRODUCTION

There has been increasing interest in using wetlands as interface ecosystems for wastewater treatment since early studies demonstrated their effectiveness at removal of nutrients and suspended solids. These included use of cypress swamps in Florida (Odum et al., 1977; Ewel and Odum, 1984) and peatlands in northern Michigan (Kadlec and Knight, 1996). Constructed wetlands using surface-flow or subsurface flow emergent vegetation or aquatic plant systems have gained increasing acceptance (Hammer, 1989; Mitsch and Gosselink, 1993; Reed et al, 1995). Since such natural or constructed wetlands are often limited by solar insolation and show increased rates of uptake in warmer climates, such systems may be expected to operate even more efficiently in milder Mediterranean, subtropical and tropical regions than in the continental US and northern European conditions where they were first developed and where they are however still in great use, although much greater surface in necessary to achieve same levels of treatment. Constructed wetlands can also be made increasingly responsive to on-site sanitation situations (as opposed to centralized sewered sanitation), where lack of localized treatment presents great public health risks, as in the case of the majority of African, South American and Asian countries (Koottatep et al, 2002).

But the potential advantages in using constructed wetlands extend far beyond their efficacy for improving human health by preventing disease transmission through contact or through pollution of sources of potable water. Constructed wetlands offer more than simply an alternative and low-cost, low-maintenance form of wastewater "treatment". In an expanded paradigm, more suited for the current global situation, sanitation specialists should take advantage of their potential role in water conservation, through greening, creating diverse landscapes and irrigating potentially harvestable plants through the re-use of the wastewater, thus saving higher quality or potable water which might otherwise have been applied.

The Wastewater Gardens ecotechnology was inspired by the experience in the Biosphere 2 closed ecological facility (Allen, 1991, Alling and Nelson, 1994). There the lead author (MN), a member of the eight-person crew for its initial two year closure experiment, was responsible for operation and research of the constructed wetland system which treated and recycled all the wastewater effluent from the people, workshops, laboratories and domestic animals. This system, which was partially open channel with floating wetland plants and also included soil areas with emergent (rooted) wetland vegetation, was designed in consultation with Wolverton, a NASA researcher and U.S. pioneer of such systems (Wolverton, 1987).

The Biosphere 2 constructed wetland was housed in two systems comprising fiberglass tanks with a total area of 41m2 which treated 1-1.2 m3 of wastewater daily. Sedimentation tanks preceded the wetland and were discharged by batch loading when full. Residence time in the constructed wetlands was four days and BOD removal was >75% (Nelson et al, 1999).

The constructed wetland operated as far more than a "treat and dump" sewage treatment plant. It was biodiverse with 14 species of vascular plant, including ones with beautiful foliage and flowers. The wetland also provided habitat for beneficial insects, such as ladybugs and frogs, which were a part of the integrated pest management approach for the Biosphere 2 agricultural area. The foliage was harvested and fed to goats, pigs and chickens inside the facility. A total of over 1200 kg dry weight was harvested during the two years. The treated effluent from the constructed wetlands was treated with UV light for sterilization and was added to the irrigation supply for the Biosphere 2 farm thus ensuring complete return of nutrients to the soils.

Figure 1. Three of the fiberglass tanks which housed one of the two constructed wetland systems inside Biosphere 2. Shown soon after closure, the system included 14 floating and rooted wetland species and provided additional habitat as well as attractive foliage.

Figure 2. The Biosphere 2 constructed wetland plants were harvested periodically and supplied 1200 kg dry weight of fodder to the domestic animals. Treated effluent was added to the irrigation supply tanks, returning nutrients to the soils.

DEVELOPING PILOT PROJECTS IN MEXICO AND WORLDWIDE

After Biosphere 2, further development of the approach occurred with pilot project wetlands using subsurface flow being created along the Yucatan coast to help with removal of nutrients and other sewage pollutants harmful to coral reefs and marine organisms (Pastorok and Bilyard, 1985). Subsurface flow wetlands was chosen because they have little potential for malodor, serving as a breeding ground for mosquitoes nor accidental human contact – since the wastewater is kept at least 5 cm beneath a dry layer of gravel. They are also very passive systems, not requiring pumps or electricity, and as such have advantages in terms of cost, maintenance requirements and the need for purchased equipment and replacement parts. These characteristics also make them more suitable for onsite treatment close to houses or businesses (EPA, 1993; Cooper, 1992; TVA, 1993). In such installations, continuing to make the constructed wetlands biodiverse, attractive gardens, led to use of the term "Wastewater Gardens" to differentiate this approach from the monocultural systems which use only one or two species, most commonly *Phragmites australis*, and/or *Typha latifolia*.

Ecological theory furthermore supports the contention that high biodiverse systems may offer advantages. Wastewater interface ecosystems 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).

Accordingly, both in the Yucatan wetlands and the many systems that followed, in both warm and cold climates, the systems were made as biodiverse as possible, including the trial and demonstration of plants not previously known to be water-tolerant. The potential of the constructed wetlands to produce crops of harvestable materials has been long known and little practiced. For example, during the 1970s, during periods of high oil prices after the formation of OPEC, there was interest in using wastewater to grow fast-growing trees as biomass energy crops and as sources of timber and this potential use is still attractive (Nelson, 1995).

Initial results, using 3-4 m^2 of subsurface flow wetland per full-time inhabitant, from the early Wastewater Gardens were quite good (Nelson, 1998a, Nelson, 1998b) and in the decade since the systems have been implemented in countries such as the Bahamas, Belize, France, Indonesia (Bali and Sulawesi), the Philippines, Poland, Spain, Portugal and the United States (www.wastewatergardens.com).

SYSTEM IMPROVEMENTS: CHANGING THE PARADIGM TO TOTAL REUSE

Experience with implementing Wastewater Gardens in many countries and climates around the world has led to system improvements such as increased length to width ratios to reduce the chance of short-circuiting of the water and to maximize residence time. It was also recognized that low maintenance is not the same as no maintenance – any system requires maintenance. To maintain high diversity for example, it may be necessary to prevent shading of understory plants through periodic pruning of the taller vegetation. Accordingly, maintenance manuals and training was strengthened. The need is now emphasized that attention must be paid to critical issues, such as proper pumping of septic tanks to remove solids when necessary, periodic checking of septic tank filters, pruning for maintaining good numbers and diversity of vegetation, especially that of deeper-rooted wetland plants, and removal of any organic matter which begins to build up on the gravel surface in order to avoid excessive sedimentation.

A major paradigm change in the design of more recent Wastewater Gardens systems was realizing that a constructed wetland system does not end with discharge of treated effluent. The goal should be total productive use of water and nutrients – not simply the level of removal of pollutants in the constructed wetland. This has changed our conception from the old paradigm of "final disposal, e.g. leach drains" to incorporating greywater recycle/irrigation where possible and designing a robust subsoil irrigation of the treated effluent from the Wastewater Gardens. The goal is total recycling/reuse of wastewater, not simply "treatment" (see Figure 3). This also greatly increases the amount of "greening" possible – since the subsoil irrigation area usually is larger (depending on soil permeability and climatic factors for its sizing) than the footprint of the constructed wetland. Since this final stage of the system only uses the treated effluent as subsoil irrigation, one is not limited to use of only wetland plants which increases the possibilities for productive plantations (fruit, timber trees; medicinal plants; cut flowers). The only plants which should not be used are root crops or salad greens, since the water though far cleaner than the raw sewage is not sterilized, or species with invasive root systems which might interfere with the subsoil irrigation tubing.

For situations which demand higher initial treatment performance, or which lack available space, use of vertical flow design which results in better aeration and thus reduction of N and BOD may be indicated. These vertical flow systems generally require use of dosing siphons or pumps to ensure batch-loading and are thus more technically-demanding and reliant on electricity. It must be remembered however that vertical flow wetlands achieve their higher "removal" of nitrogen for example by facilitating the aerobic conditions where organic nitrogen is chemically transformed into its gaseous state. While this helps meet regulations for nitrogen in sewage discharge water, if the goal is to further utilize the nutrients for subsoil irrigation, this nitrogen is lost and degraded back into gaseous nitrogen from its far more useable form as organic nitrogen. There is an as yet unresolved contradiction between the increased desire to reuse and recycle wastewater nutrients and regulations which stipulate very low levels of nitrogen, regulations which were developed and are more appropriate when sewage treatment ends with discharge to oceans, lakes or rivers.

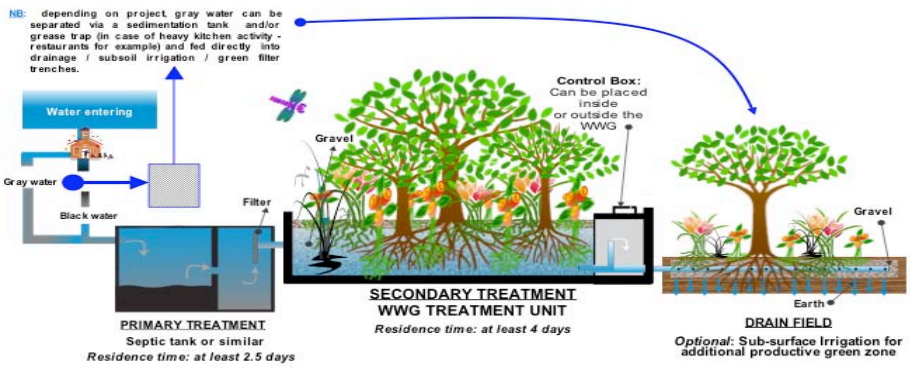


Figure 3. The three steps of a typical Wastewater Garden system: septic tanks or Imhoff tanks or similar primary treatment (for larger applications), the WWG unit itself and the final use of the treated effluent in as subsoil irrigation.

CASE STUDY 1: PANDANAS PARK ABORIGINAL COMMUNITY, DERBY, WEST AUSTRALIA

In 2007 and 2008, the Pandanas Park Aboriginal Community received Australian government Community Water Grants to install Wastewater Gardens. The grants were supplemented by matching funds from the Aboriginal Housing Unit of the West Australian Department of Housing and Works. The community, located very close to the Fitzroy River in the Kimberley region of northwest West Australia, was seeking to protect the river and groundwater from sewage pollution while greening the community. Community Water Grants were instituted to encourage practices which result in water conservation especially with new and innovative technology. If the community were to achieve significant greening by using its wastewater rather than drawing on higher quality water, the water savings would be significant. In addition since Wastewater Gardens systems previously installed in the Kimberley had demonstrated 90+% reductions of BOD_5 and suspended solids, 98% reduction of fecal coliform bacteria, 50-70% reduction of nitrogen and 30-58% reduction of phosphorus (Table 1 and Table 2), groundwater and drainage to the Fitzroy River would be protected from pollution.

Table 1. Summary of Water Quality Tests at Emu Creek (Gulgagulganeng) Aboriginal Community Wastewater Gardens System, Kununurra, West Australia. Tests performed at MPL Laboratories, Perth, Australia, an accredited testing facility from August 2002 – May 2004.

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

Table 2. Summary of Water Quality Tests at Birdwood Downs Wastewater Gardens System, Derby, West Australia. Tests performed at MPL Laboratories, Perth, Australia, an accredited testing facility from September 2000 – April 2002.

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 Gardens discharge	12	16.5	27	7.3	116,000
Percent Reduction	95%	95%	48%	30%	98.2%

Five Wastewater Gardens systems were installed to service eight houses and a childcare facility at the community. There were existing septic tanks at the houses and to take advantage of existing infrastructure, these were utilized. The new design routed the effluent from these septic tanks to the new Wastewater Gardens and in the leach drain areas, another planting of "wastewater ecoscape" plants was done to maximize greening of the community. Two of the systems serve three houses each since the houses were close enough to permit their septic tank effluent to be led to a common WWG treatment unit. To ensure that none of the systems require pumps, all of the WWGs are in effect "sunken gardens" since lowering their surface 30-50 cm below ground level permitted the necessary 1% slope from septic tank to entry/header pipe to be accomplished through gravity-flow (Figure 4).

The Wastewater Gardens units are planted with a variety of tropical fruit trees, flowering shrubs, wetland ferns and trees compatible with the tropical savannah climate of the Kimberley region (Figure 5). The mean annual rainfall at this site is around 675mm which is concentrated during a wet season from December through April when 90% of rainfall is concentrated. Temperature maximum and minimum means are 34.5 deg. C. and 21.6 deg. C. respectively (with high/low extremes of 44.5 deg. C. and 6 deg. C.). PET (potential evapotranspiration) is high, over

3200mm per year, ranging from a low daily mean of 7.4 mm. to 12.5 mm. with a mean daily PET of 9.2 mm. The climate is both extreme and highly variable – annual rainfall has varied from 185mm to 1250 mm, and single day rainfalls of 290mm have been recorded during tropical cyclone events. So it is important that constructed wetlands which will receive direct rainfall have sufficient berms, adequate size piping, and robustly designed subsoil leach drain trenches to prevent any overflow, facilitate rapid movement of water and prevent surfacing of wastewater during heavy rainfall events.

Plants which have been used in fifteen Kimberley WWG installations implemented since 2002, including Pandanas Park Aboriginal Community, include: banana (*Musa* spp.) and plantain, papaya (*Carica papaya*), coconut (*Cocos* spp.), sea grape (*Cocoloba uvifera*), *Heliconia* spp., fantail palm, pandanas palm (*Pandanas pandan*), *Canna edulis* (canna lilly), elephant ear (*Xanthosema roseum* and *Alocassia macrorhiza*), wetland fern (*Acrostichum sp.*), Leichardt pine (a native *Ficus* species), snake's tongue, papyrus (*Cyperus* spp.), *Ixora*, oleander (*Nerium oleander*), *Alimander* spp., native paperbark species (*Melaleuca* spp.), mint, hibiscus (Hibiscus rosa), vetiver grass, crotons, Darwin palm, ginger and cardamom (Figure 5).

The "wastewater ecoscapes" at Pandanas Park comprised areas planted to reflect Kimberley native plants – flowering shrubs and trees, including food crops known as "bush tucker plants" (Figure 6). A supplemental surface irrigation system, using soaker hoses controlled by a timer in a secure control box (to minimize accidental disruption of settings or equipment by children) will be used for the first two years to ensure establishment of the native plants, after which time that system will be removed. The plants will be able to survive on just rainfall, but are expected to grow more rapidly because their roots will be benefitting from the treated effluent being dispersed in the subsurface leachdrain trenches.

Native plant species used in the Wastewater Ecoscapes (Figures 6) included: (medium-sized trees): *Ficus racemosa, Lophostomon grandifloris, Malaleuca cajuputi, Malaleuca vindiflora;* (small wetland trees): *Banksia dentate, Leptospernum modinum, Livistonia eastonii, Eremophyllia bignoniflora, Exocarpus latiflorus;* (small shrubs): *Jasminum didymium, Acacia deltoidea, Acacia retevenea, Grevillea dryandei, Pteocaulon sphaceclatum, Hibiscus pentaphyllus, Hibiscus setulosus;* (medium shrubs): *Carissa spinarum, Cyanostogia cyanocalyx, Santalum lanceollatum, Gossipium australae, Gosypium sturtianum, Grevillea cunninghamii, Ipomea costata, Eremophylia fraseri, Floeggia virosa*; (tall shrubs): *Grevillea wickhamii, Grevillea heliosperma, Grevillea refracta, Grevillea mimata, Acacia ampliceps, Acacia dunnii, Acacia platycarpa, Gardenia pyridiformis, Eucalyptus paohyphilla;* (ground cover plants): *Solanum beuglahelei, Acacia adoxia, Acacia hilliana, Polycarpa longiflora, Enchylaena tormentosa, Ptilotus macrocarpus, Gomphrena flaccida,* and *Abutlinon* sp.

Pandanas Park community members were involved in the construction and fencing of the systems to encourage a sense of ownership of the systems and a training program is planned to transmit the care necessary for their continued maintenance.

a b c

Figure 4 a, b, c: steps in the construction of the Wastewater Gardens at Pandanas Park Aboriginal community including water-testing of the EPDM liner, filling the WWG with gravel and the system with rock-covered sides of the sunken gardens and showing the header pipe and I/Os for the collector pipe.

Figure 5. One of the five Wastewater Gardens systems at Pandanas Park Aboriginal community, Derby, West Australia. This one receives the effluent from three individual house septic tanks. The system is a “sunken garden” so that gravity-flow is sufficient to bring wastewater to the inlet pipe. Shown here after its first year growth.

Figure 6a. One of the native plant "Wastewater Ecoscapes" at Pandanas Park Aboriginal community which is subsoil-irrigated by treated effluent from the Wastewater Garden. A supplemental drip irrigation system with soaker hoses will be used to ensure establishment of the vegetation for the first two years, then disconnected. Pictured here after about 10 months growth from small seedlings.

Figure 6b. Two views of the wastewater ecoscapes planted with native Kimberley species at Pandanas Park Aboriginal community showing excellent development after one year's growth.

CASE STUDY 2: WASTEWATER GARDENS AT TEMACINE, ALGERIA

In April/May 2007, a pilot Wastewater Gardens system, to our knowledge the first constructed wetland in Algeria, was constructed in Temacine, middle/southern Algeria, in the heart of a date plantation region. The project was funded by the Algerian Government Ministry of Water Resources, Department of Sanitation and Environmental Protection (Ministère des Ressources en Eau (MRE) - Direction de l'Assainissement et de la Protection de l'Environnement (DAPE/MRE), and the town of Temacine, with the support of the Belgian Technical Cooperation for the study and training part of the project. The WWG system was chosen to test constructed wetlands for up to then untreated raw sewage and designed to be part of the restoration of the local historic Ksar, a caravanserai city built with traditional adobe (sun-dried bricks) raised on date palm trunks, which was destroyed by torrential desert rains some half-century ago. Covering $400m^2$ and in the shape of a crescent moon (Figure 7a), the Wastewater Gardens system is sized to handle 15 m^3, daily wastewater effluent of 100-150 people, some of whom have rebuilt their homes in parts of the old Ksar, including the water coming from one of the local Mosque.

The local climate is marked by low and erratic rainfall mostly falling in the winter months, high year-round PET, very high summer temperatures and cold winters with occasional light and short freezing conditions. Yearly precipitation averages just 72mm but there can be torrential rains, although these may not occur for decades or longer. Maximum/minimum temperatures average 40 deg C./26 deg C. in August and 17 deg C./5 deg. in January. PET is lowest in the winter months, when it averages 1.86 mm/day in December and 2.14 mm/day in January, but is over 9 mm/day in June and around 10 mm/day in July and August. Additional stress is placed on vegetation by very hot and dry, strong blowing winds, among which the Sirocco, causing often sandstorms which are countered by wind-barriers around date plantations of woven date fronds.

The region, on the edge of the Sahara, suffers from serious and multiple water problems. To irrigate the expanding area of date plantation, water is pumped from increasing depth (up to 900 m) – essentially tapping fossil, irreplaceable water resources. This water contains salts which compounded by the high evapotranspiration rates in the desert climate has led to increasing salinity of drainage water and soils. This in turn prompts heavier use of irrigation water to attempt to leach salts out of the soil – leading to there being a shallow water table often just a meter beneath the soil of increasingly saline content. This problem forced the French during their presence in the country to build a drainage canal, which now extends over 150 km long towards the Tunisian border. The canal is increasingly polluted by residential raw sewage from an expanding local population attracted by the relative wealth, agricultural promise and safety of the region during the recent period of domestic strife. The residential sewage flows or is pumped, completely untreated, into the drainage channels and thence into the canal which once supported fish but which now suffers from eutrophication, salination and contamination with sewage pathogens. (Figure 7e).

The Temacine WWG system currently operates partly by gravity flow from the current Ksar's habited houses and the Mosque (for a volume of $2.5m^3$/day +/- out of the $15m^3$ total) which have an elevation > 5m above the abandoned field where the system is located). Eventually, all the wastewater will be directed into the system by gravity-flow as more houses in the Ksar are rebuilt, but at present the remaining sewage water is pumped from a nearby lift station where raw sewage is received and pumped towards the canal.

A septic tank of $37.5m^3$ was built to provide 2.5 days residence for the $15m^3$ of daily wastewater as primary treatment. After passing through a filter at the outlet of the septic tanks made out of natural fiber (the bark of the nearby palm trees – Figure 7b), the water flows under the road to the inlet pipe of the WWG unit.

The authorities, using a local construction contractor, preferred to build this initial system with a concrete liner, rather than an imported geomembrane like EPDM as concrete represents more labor and thus jobs for the local economy. Accordingly, the 400 m^2 system has a weld mesh-reinforced concrete pad 10mm deep, and walls of concrete block, tied into the pad with rebar and reinforced with horizontal and vertical steel rebar, plastered to make them water-tight. Along the upper arc, the system is around 65m long with a maximum width of around 18m. A series of seven baffles constructed of concrete block is designed to force the water around each obstacle, like a meandering stream, and to work against short-circuiting and reduction of design residence time (Figure 7c). Gravel to a depth of 60 cm fills the WWG basin and the 110mm PVC pipe used for inlet/header and collectors in the system are positioned to allow 10-15 cm of dry gravel above the standing water level in the system. Since the land used for the WWG system is surrounded by date plantation and drainage channels, water is found 50-70 cm below the soil surface. That situation combined with the clay soil impaired by compaction resulting in relatively low permeability, required a leach drain with around 500m of subsoil gravel-filled trenches to assure proper distribution of the treated effluent from the WWG unit (Figure 7d).

Figure 7a. Several stages of the construction of the Wastewater Gardens at Temacine, Algeria. *Top left*: excavation begins of the basin; *top right*; after the concrete floor slab is poured, concrete blocks with steel reinforcing make the side walls; *Middle left*: walls are plastered and baffles made inside the basin to make water flow more slowly through the system; *Middle right*: control box with airtight lid is installed and subsoil irrigation, leachdrain trenches (still in excavation) begun. *Bottom left*: view from the old Ksar of 37.5m^3 septic tank (foreground), planted WWG and leach drains. *Bottom right*: closer view of WWG plants a few months after planting.

Figure 7b. Close-up of the local material used for the filter at the exit of the sewage water of the primary treatment.

Figure 7c. Buffer walls to ensure sewage water's proper residence time and avoid short-circuiting.

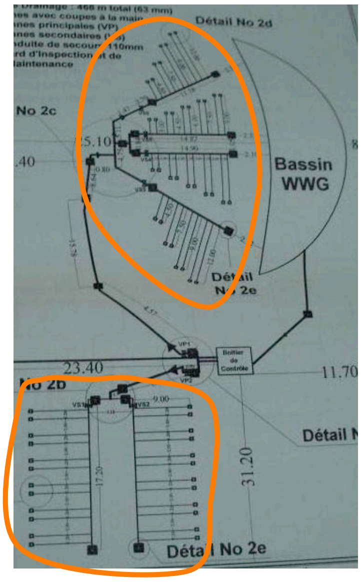


Figure 7d. Plan of the WWG unit's drainage system: 468 meters drainage in 2 major areas (orange lines) and 6 sub-sections, gravity flow.

Figure 7e. Partial view of parts of the drainage canal, with incoming raw sewage water, transforming itself in a repository of untreated waters

The aim of this pilot unit was not only to reach relatively high treatment parameters as subsequent measures have confirmed, but also especially to highlight a constructed wetland's capacity to carry a highly diverse plant community, with a majority of plants having an important useful or marketable value. 21 species were used in the Wastewater Gardens unit (Figure 9) and include: fig tree (*Ficus carica*), vetiver grass (*Vetiver zizanioides*), *Laurus nobilis*, jasmine (*Jasminum grandiflora*), lantana (*Lantana camara*), local roses (Touggourt, Damascus and Syrian rose), hibiscus (*Hibiscus rosa sinensis*), oleander (*Nerium oleander*), several local mints (*Mentha spicata*), papyrus family (*Cyperus* spp.), goat's leaf (*Lonicera caprifolium*), *Pelargonium rosa*, pomegranate (*Punica granatum*), *Morus nigra*, saltbush (*Atriplex halumis*), cattail (*Typha latifolia*), silk cotton palm (*Washingtonia* spp.), lemon grass (*Cymbopogon citratus*), *Juncus* spp., and canna lily (*canna edulis, canna indica*).

Due to a late implementation date however, for project's logistics' imperatives, the WWG unit's plantation occurred very late in the season, about 3 weeks prior to the beginning of high summer heats and wind/sand storms. While 99% of the plants grew very well during the first month of the wetland's life, a strong Sirocco wind then began to blow and seems to be the cause for a loss of about 50% of the plants. So that by May of 2008, the total number of species had been brought down to 12 species in total, all of which are continuously growing, flowering and thriving. Future replanting is planned for the next local spring so that the WWG unit can be brought once again close to the initial plant diversity.

The drainage area was planted with over 100 fruit trees (species with non-invasive roots) but the great majority have also not survived, this time the reason seeming to be not only the late plantation date, but also a rising underground water table with extremely high salt content, although the investigation is still underway as this paper is written. Replanting is also to take place also in the spring of 2009.

Figure 9. Overview and close-up of some of the species initially planted: Canna, Oleander, Papyrus, Hibiscus, Roses, Papaya, Banana and Vetiver.

Despite this loss of vegetation, water quality tests during the first year of operation have shown adequate and expected levels of treatment in the Wastewater Gardens unit, although we are concerned about general maintenance of the system, in terms of the complementary flow of water which hasn't been steady, as well as the regularity of the septic tank's change of filter material. Over 93% reduction of COD and BOD^5 has resulted in effluent water of 35 mg/l and 25 mg/l respectively, and 43% and 50% of nitrogen and phosphorus reduction from influent septage (Table 3). The aimed treatment levels were also reached (Table 4a, 4b, 4c, 4d).

Table 3. Water Quality tests 2007-2008 at the 400m2 Wastewater Gardens system in Temacine, southern Algeria.

Water Analysis Summary

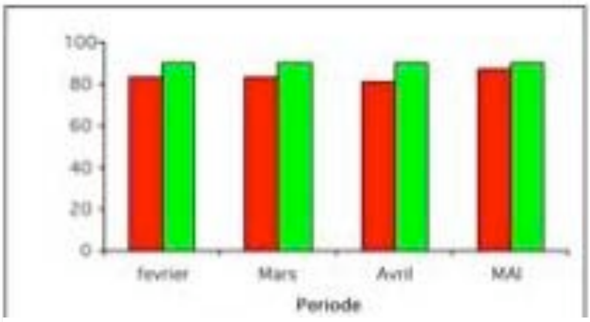
Parameters	BOD^5	COD	TSS	PO^4	NO^3	NO^2	PH	T° (°C)	O2 Dissolved
In (mg/L)	450	563	837	31	35	1.27	7,33	35,6	0,31
Out (mg/L)	25	35	49.5	15.5	20.2	0.29	7,48	32,3	0,94
Reduction	*94,4%*	*93,8%*	*94%*	*50%*	*42,3%*	*77%*			

Analysis 1: August 2007

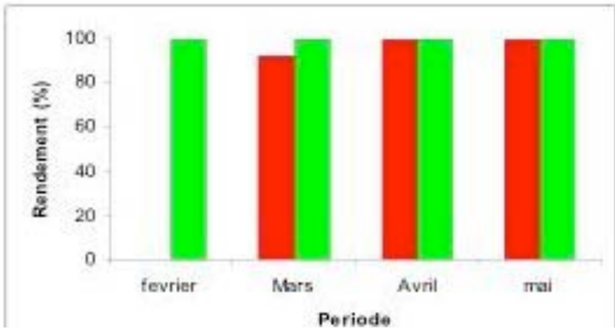
Parameters	BOD^5	COD	TSS	PO^4	NO^3	NO^2	PH	T° (°C)	O2 Dissolved
In (mg/L)	240	590	522	33	35	2,3	7,9	19,1	0,03
Out (mg/L)	31	50	29	15	14	0.63	8,5	13,9	0,8
Reduction	*87%*	*91,5%*	*94,4*	*54,5*	*60%*	*72,6%*			

Analysis 2: January 2008

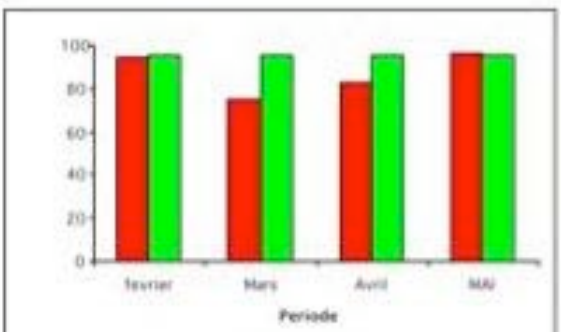
Table 4. Average adequation between purification levels aimed at during design and construction of the WWG constructed wetland (April/May 2007) and actual results (February-May 2008)



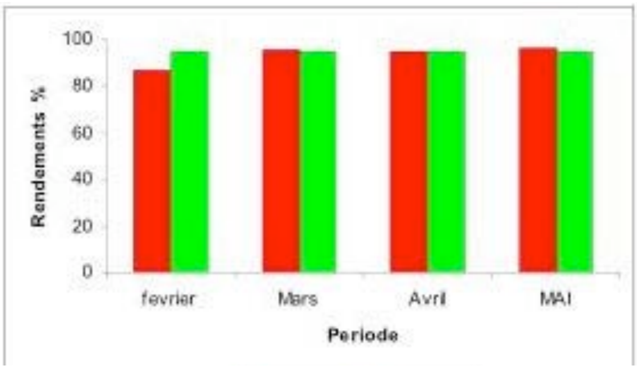
COD levels reached **COD levels aimed**



Coliform Bacteria levels reached **Colf. Bact. levels aimed**



BOD^5 levels reached **BOD^5 levels aimed**



TSS levels reached **TSS levels aimed**

CONCLUSIONS

The two case-studies presented, that of an Aboriginal community in the tropical savannah of NW Australia and in the arid, high summer/cold-winter desert region of southern Algeria, demonstrate the range of conditions to which constructed wetlands may be successfully applied. In such remote locations, there is growing appreciation that systems that require a highly technological infrastructure are neither sustainable nor affordable, and would be difficult to maintain. More natural systems, making use of the principles of ecological engineering

(Jorgensen and Mitsch, 1991) are increasingly gaining favor since they utilize time-tested ecological mechanisms. Therefore, constructed wetland approaches like Wastewater Gardens seem an appropriate solution since they rely to a much greater extent on local resources and natural elements and far less on imported and mechanical equipment and chemicals (Nelson et al, 2001). Rather than becoming a net contributor to energy use and excess CO^2 production, constructed wetlands by adding additional green zones can help in sequestering carbon and produce O^2 through the increase of plant biomass. High-diversity systems provide ancillary benefits such as harvestable and decorative plants and attractive landscape greening, especially valuable in harsh environments. Such approaches offer significant value additives to their primary purpose in preventing pollution and improving human health through prevention of impairment of potable water sources. In this growing era where water resources are properly understood to be in scarce supply and high demand, their value will be appreciated from the standpoint of water conservation in substituting recycled water in place of higher quality water for use in irrigation and greening the environment.

The arguments in favor of using constructed wetlands are numerous, provided there if land available, as they exemplify intelligent design, meaning making the maximum use of each resource, minimizing energy expense, being adaptable to a wide range of situations and being robust. Nature has had the benefit of a pretty long R & D period! (Pawlin, 2007).

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