VETIVER SYSTEM FOR ENVIRONMENTAL PROTECTION

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1. INTRODUCTION

The Vetiver System (VS), which is based on the application of vetiver grass (*Vetiveria zizanioides*), was first developed by the World Bank for soil and water conservation in India in the 1980s. In addition to its very important application in agricultural lands, scientific research conducted in the last 10 years has clearly demonstrated that VS is also one of the most effective and low cost natural methods of environmental protection. As a result VGT is now increasingly being used worldwide for this purpose. For this reason, vetiver grass is known as a wonder grass, a miracle grass and a magic grass in various parts of the world

The two main factors that contributed to the global application and acceptance of VS are, firstly, the availability of scientific data to back up anecdotal field observation and also to provide explanations to vetiver's phenomenal and unique characteristics, and secondly, its promotion through The Vetiver Network by Dick Grimshaw.

In term of environmental protection, the most significant breakthroughs are firstly research leading to the establishment of benchmark tolerance levels of vetiver grass to adverse soil conditions and heavy metal toxicities in the last 12 years. This has opened up a new field of application for Vs: the rehabilitation of toxic and contaminated lands. Secondly the ability of vetiver to tolerate and absorb agrochemicals and nutrients in polluted water has direct applications in environmental protection as a phytoremedial measure. Thirdly research on structural and shear strength of vetiver roots has indirect application to environmental protection via erosion and sediment control in infrastructure construction.

VS can protect the environment in at least four ways: terrestrial, aquatic, aerial and social environments. But this paper presents the state of knowledge of the proven and potential applications of VS on the wastewater problem, now and in the future.

2. SHORTAGE OF CLEAN WATER

" Water, water everywhere, nor a drop to drink"
Samuel Coleridge

These words from the famous English nineteen-century poet sound like a 21st century statement, when fresh water scarcity is predicted to become the greatest single threat to international stability, human health, global food supply, poverty and even the spectre of war. According to the World Resources Institute, within 25 years, more than half of the world population will be suffering severe fresh water shortages. This looming crisis is reflected by a host of international conferences in the last few years.

So what is the solution? Desalinization of seawater and chemically treated polluted and contaminated water are energy-hungry and very costly that most developing countries cannot afford. But most importantly, the by-products of these treatment processes, such as salt and concentrated toxic materials are often themselves, a bigger problem.

Application of the Vetiver System for wastewater treatment is a new and innovative phytoremedial technology, which has the potential to meet all the right criteria. It is a natural, green, simple, practicable and cost effective solution and most importantly, its by-product offers a range of uses from handicrafts, animal feeds, thatches, mulch and fuel just to name a few.

This paper presents the state of knowledge of the proven and potential applications of VS in the field of environmental protection and phytoremediation.

3. How Vetiver System can Reduce this Impact?

The Vetiver System can reduce the impact of this imminent global crisis in two ways by:

- **Reducing the volume or eliminating the contaminated wastewater** by:
  - Land irrigation
  - Wetland

- **Improving the quality of wastewater** and polluted water by:
  - Trapping debris, sediment and particles
  - Absorbing pollutants and heavy metals,
  - Detoxification of industrial and agrochemicals in wetlands

4. HOW DOES THE VETIVER SYSTEM WORKS?

Earlier research conducted to understand the role of the extraordinary physiological and morphological attributes of vetiver grass in soil and water conservation, discovered that vetiver grass also possesses some unique characteristics suitable for environmental protection purposes (Truong, 2004). Extensive research in Australia, China and Thailand and in other countries has established vetiver tolerance to elevated and sometimes toxic levels of salinity, acidity, alkalinity, sodicity as well as a whole range of heavy metals and agrochemicals.

Latest research also shows its exceptional ability to absorb and to tolerate extreme levels of nutrients (Wagner *et al*. 2003), to consume large quantities of water in the process of producing a massive growth (Truong and Smeal, 2003). These attributes indicated that vetiver is highly suitable for treating polluted wastewater from industries as well as domestic discharges.

5. SPECIAL MORPHOLOGICAL AND PHYSIOLOGICAL FEATURES OF VETIVER GRASS SUITABLE FOR EFFLUENT DISPOSAL

- Stiff and erect stems which can stand up to high velocity flows
- Thick growth, forming a living porous barrier which acts as a very effective filter, trapping both fine and coarse sediment
- Deep, extensive and penetrating root system which can reduce/prevent deep drainage
- Highly resistance to pests, diseases and fire Tolerance to extreme climatic variation such extreme temperature from -15^{o} C to 60^{o} C.
- Tolerance to prolonged drought, submergence and flood
- Highly tolerant to soil high in acidity, alkalinity, salinity, sodicity and magnesium
- Highly tolerant to Al, Mn, As, Cd, Cr, Ni, Pb, Hg, Se and Zn in the soil
- High level of tolerance to herbicides and pesticides
- Highly efficient in absorbing dissolved N, P, Hg, Cd and Pb in polluted water (Truong and Baker, 1998)
- Vetiver uses more water than other common wetland plants such as *Typha* spp, *Phragmites australis* (cay say) and *Schoenoplectus validus*.
- Under wetland conditions vetiver used approximately 7.5 times more water than Typha (Cull *et al.* 2000).
- Ability to regrow very quickly after being affected by the above adverse conditions after growing conditions improved or soil ameliorants added

6. REDUCING OR ELIMINATING THE VOLUME OF WASTEWATER

For large-scale reduction or total elimination of wastewater, vegetative methods are the only feasible and practicable method available to date. In Australia, tree and pasture species have in the past been used for the disposal of leachate, domestic and industrial effluent.

To quantify the water use rate of vetiver, a glasshouse trial showed a good correlation between water use and dry matter yield. From this correlation it was estimated that for ***1kg of dry shoot biomass, vetiver would use 6.86L/day***. If the biomass of 12-week-old vetiver, at the peak of its growth cycle, was 40.7t/ha, an hectare of vetiver would potentially use 279KL/ha/day (Truong and Smeal, 2003). Latest data from a landfill leachate site shows vetiver can dispose up to 3.8L/m2/day.

6.1 Land irrigation

6.1.1 Disposal of septic effluent

In Australia The first application of the VS for effluent disposal was conducted in 1996, this trial demonstrated that planting about 100 vetiver plants in an area less than $50m^2$ have completely dried up the effluent discharge from a toilet block in a park, where other plants such as fast growing tropical grasses and trees, and crops such as sugar cane and banana have failed (Truong and Hart, 2001).

6.1.2 Disposal of landfill leachate

Disposal of landfill leachate is a major concern to all large cities, as the leachate is often highly contaminated with heavy metals, organic and inorganic pollutants. In Australia this problem can be solved by irrigating vetiver planted on the top of the landfill mound. Results to date have been excellent, the growth was so vigorous that during the dry period, there was not enough leachate to irrigate the vetiver. This planting of 3.5ha has effectively disposed of 4 ML a month in summer and 2 ML a month in winter (Percy and Truong, 2005)

6.1.3 Disposal of industrial wastewater

In Australia, the disposal of industrial wastewater is subjected to the strict environmental guidelines enforced by the Environmental Protection Authority. The most common method of treating industrial wastewater in Queensland is by land irrigation, which is presently based on tropical and subtropical pasture plants. However with limited land area available for irrigation, these plants are not efficient enough to sustainably dispose of all the effluent produced by the industries. Therefore to comply with the new standards, most industries are now under strong pressure to upgrade their treatment processes by adopting VS as a sustainable means pf deposing wastewater.

6.2 Wetlands

Natural and constructed wetlands have been shown effective in reducing the amount of contaminants in runoff from both agricultural and industrial lands. The use of wetlands for the removal of pollutants involves a complex variety of biological processes, such as microbiological transformations and physio-chemical processes, e.g. adsorption, precipitation or sedimentation.

Vetiver is eminently suitable for use as a vegetative buffer or wetland plant species due to the following morphological and physiological features (Cull *et al.* 2000):

- An ability to tolerate flooded soil conditions makes it ideal for use in ephemeral or permanent wetlands.
- The dense stand of stiff, erect stems can reduce flow velocity, increase detention time and enhance deposition of sediment and sediment-bound contaminants (eg. heavy metals and some pesticide residues).

- The dense, finely structured root system can improve bed stability and nutrient uptake, and provide an environment that stimulates microbiological processes in the rhizosphere.
- The high tolerance to elevated effluent loadings such as undiluted landfill leachate and domestic effluent.
- Most importantly its sterility should minimise its potential for becoming an aquatic weed.

6.2.1 Disposal of sewerage effluent

In Australia, under wetland conditions, vetiver had the highest water use rate compared with other wetland plants such as *Iris pseudacorus*, *Typha spp*, *Schoenoplectus validus*, *Phragmites australis*. At the average consumption rate of 600ml/day/pot over a period of 60 days, vetiver used 7.5 times more water than Typha (Cull *et al.* 2000).

A VS wetland was installed to treat sewerage effluent output from a small rural town. The aim of this scheme was to reduce/eliminate the 500ML/day effluent produced by this small town before the effluent is discharged to the waterways. The results so far has been outstanding, vetiver wetland has absorbed all the effluent produced by this small town (Ash and Truong, 2003).

In Thailand very good research has been conducted in the last few years on the application of VS to treat wastewater at various scales, in constructed wetland.

6.2.2 Disposal of wastewater from intensive animal farms

China is the largest pig raising country in the world. In 1998 Guangdong Province had more than 1600 pig farms with more than 130 farms producing over 10 000 commercial pigs each year. Therefore the disposal of highly polluted wastewater can be a major problem. These large piggeries produce 100-150 ton of wastewater each day, which included pig manure collected from slatted floors, containing high nutrient loads.

Wetlands are considered to be the most efficient means of reducing both the volume and high nutrient loads of the piggery effluent. To determine the most suitable plants for the wetland system, vetiver grass was selected along with another 11 species in this program. The best species are **vetiver**, *Cyperus alternifolius*, and *Cyperus exaltatus*. However, further testing showed that *Cyperus exaltatus* wilted and became dormant during autumn and did not rejuvenate until next spring. Full year growth is needed for effective wastewater treatment. Therefore vetiver and *Cyperus alternifolius* were the only two plants suitable for wetland treatment of piggery effluent (Liao, 2 000).

7. IMPROVING WASTEWATER QUALITY.

Off-site pollution is the greatest threat to the world environment, this problem is widespread in industrialised nations but it is particularly serious in developing countries, which often do not have enough resources to deal with the problem.

Vegetative method is generally the most efficient and commonly used for water quality improvement.
However to fulfill this task effectively, the plant species needs to be:

- Tolerant to extremely adverse growing conditions
- Tolerant to high levels of agrochemicals, heavy metals, toxic organic and inorganic compounds
- Tolerant to low nutrient levels
- Capable of producing fast growth and high dry matter yield.

Vetiver is one of a very few plants, if not a unique plant, that has the potential to meet all the criteria (Wagner *et al.* 2003; Truong, 2001).

7.1 Trapping debris, sediment and particles

7.1.1 Agricultural lands

In Australia research studies in sugar cane and cotton farms have shown that vetiver hedges were highly effective in trapping particulate-bound nutrients such as P, Ca and herbicides such as diuron, trifluralin, prometryn and fluometuron and , pesticides such as α, β and sulfate endosulfan and chlorpyrifos, parathion and profenofos. These nutrients and agrochemicals could be retained on site if vetiver hedges were established across drainage lines (Truong, 2000; Truong *et al*. 2000).

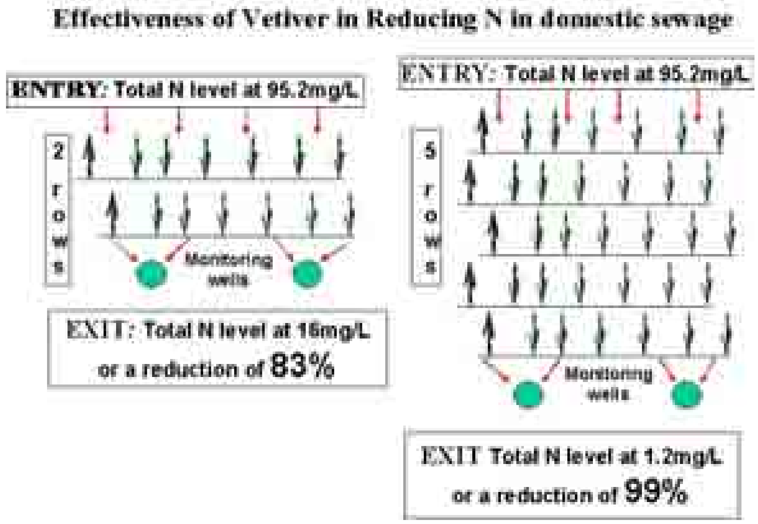
In Thailand, in experiment conducted at the Huai Sai Royal Development Study Centre, Phetchaburi Province has shown that vetiver contour hedgerows planted across the slope form a living dam, while its root system forms an underground barrier that prevents water-borne pesticide residues and other toxic substances from flowing down into the water body below. The thick culms just above the soil surface also collect debris and soil particles carried along the watercourse (Chomchalow, 2003).

7.2 Absorbing and tolerating pollutants and heavy metals

The key feature of VS in treating polluted water lies in its capacity to quickly absorb nutrients and heavy metals, and its tolerance to very elevated levels of these elements. Although the concentrations of these elements in vetiver plants is often not as high as those of hyperaccumulators, however due to its very fast and high yield (dry matter production up to 100t/ha/year), vetiver can remove a much higher quantity of nutrients and heavy metals from contaminated lands than most hyperaccumulators.

7.2.1Absorbing pollutants and heavy metals

In Australia, a project was carried out to demonstrate and to obtain quantitative data on the effect of the VS in reducing the volume of effluent and also improving the quality under field conditions. In this trial five rows of vetiver were sub-surface irrigated with effluent discharge from the septic tank. Two sets of monitoring wells were installed, one after two rows and a second one after five rows of vetiver. After five-months of growth, the total N levels in the seepage collected after 2 rows was reduced by 83% and after 5 rows by 99%. Similarly the total P levels were reduced by 82% and 85% respectively (Truong and Hart, 2001).



Hart *et al*. (2003) conducted a series of trials to evaluate the efficacy of hydroponic vetiver in treating effluent after it has been primary treated in septic tanks. Results indicate that under a hydroponic flow through system, the best method is for effluent to flow at 20 L/min through Vetiver roots. One square metre of hydroponic Vetiver can absorb 30.000mg of N and 3.575mg of P in eight days. This level is much higher than those from other crop and pasture plants grown in Australia.

These results reconfirmed earlier Chinese research showing vetiver could remove most soluble N and P in effluent over a very short period of time and thus eliminating blue-green algae in the polluted water (Anon, 1997; Zheng *et al*. 1997).

In China, nutrients and heavy metals from pig farm are key sources of water pollution. Wastewater from pig farm contains very high N and P and also Cu and Zn, which are used as growth promoters in the feeds. The results showed that vetiver had a very strong purifying ability. Its ratio of uptake and purification of Cu and Zn was >90%; As and N>75%; Pb was between 30% -71% and P was between 15-58%. The purifying effects of vetiver to heavy metals, and N and P from a pig farm were ranked as Zn>Cu>As>N>Pb>Hg>P (Xuhui *et al*., 2003; Liao *et al*,2003)**.**

In Vietnam, the banks of canals and irrigation channels in the acid sulfate soil (ASS) regions of southern Vietnam are highly erodible. Results to date indicate that on moderately acidic soil (pH >3.5) vetiver can be established easily with adequate fertiliser only, but on severe

ASS (pH between 2.5 and 3.0), vetiver grass can survive and grow only with lime application, which provides high survival and growth rates. Concentrations of some toxic elements such as Al, Fe, and SO_4 in vetiver grass were very high, much higher than those species considered tolerant to ASS. Moreover these concentrations tend to increase as the plant matures. These high concentrations indicate the level of these elements could be reduced in both surface runoff and deep drainage water, thus reducing the contamination of canal water (Le van Du and Truong, 2003).

8. PHYTOREMEDIATION WITH VETIVER GRASS

8.1 Industrial wastewater

In China, Wastewater produced from the oil refinery of the Maoming Petro-Chemical Company, Guangzhou, contains high concentrations of organic and inorganic pollutants, therefore it cannot be discharged directly into river or sea unless being treated first. Four plant species, *Vetiveria zizanioides*, *Phragmites australis*, *Typha latifolia*, and *Lepironia articutala* were used in a vertical flow wetlands to test their efficiencies in the purification of oil refined wastewater and their growth in wetlands soaked with oil refined wastewater. The results obtained from a 2-month trial indicated that the purifying rates of constructed wetlands for oil-refined wastewater were all very high at the beginning, but the performance decreased and became basically stable as time passed (Xia *et al*. 2003).

8.2 Mine wastewater

Acid mine drainage (AMD) released from mining industries usually has a low pH and contains high heavy metals levels, which significantly impacts on water quality and ecosystems in southern China. A test was conducted to assess the tolerance of six wetland species to AMD collected from Lechang lead/zinc mine tailings. Among the six plants tested, vetiver had high tolerance to the AMD. (Wengchen, 2003)

8.3 Mine tailings

Due to its high tolerance levels of heavy metals and other extremely adverse conditions in the soil, vetiver has been used very effectively as a phytoremediation method for mine solid wastes such as mine tailings.

In Australia and South Africa, VS has been use successfully for wind and water erosion control in coal, gold, platinum, bentonite, lead/zinc and bauxite mines (Truong, 2004)

In China, at Lechang lead/zinc mine in Guangdong, vetiver has been used quite extensively to rehabilitate the tailings. (Wengchen, 2003).

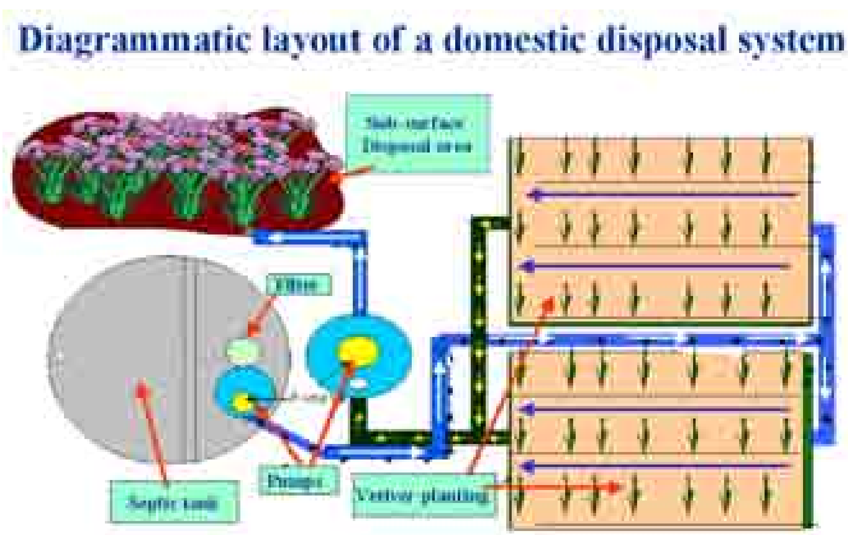
9. FUTURE TREND

As water shortage is looming worldwide, wastewater should be considered as a resource rather than problem. ***The current trend is to recycle wastewater for domestic and industrial uses,*** instead of disposal. Therefore the potential of VS is enormous as a simple, hygienic and low cost means of treating and recycling wastewater resulting from human activities.

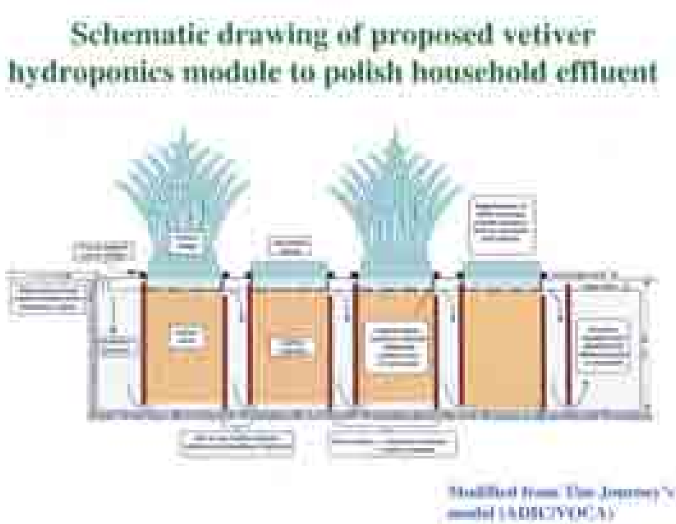
9.1 Domestic wastewater recycling/treatment

After treating in the vetiver bed, domestic sewage effluent is use for gardening.

9.1.1 Recycling for domestic uses.



9.1.2 Recycling for small business uses such as hotels, shopping centers etc.

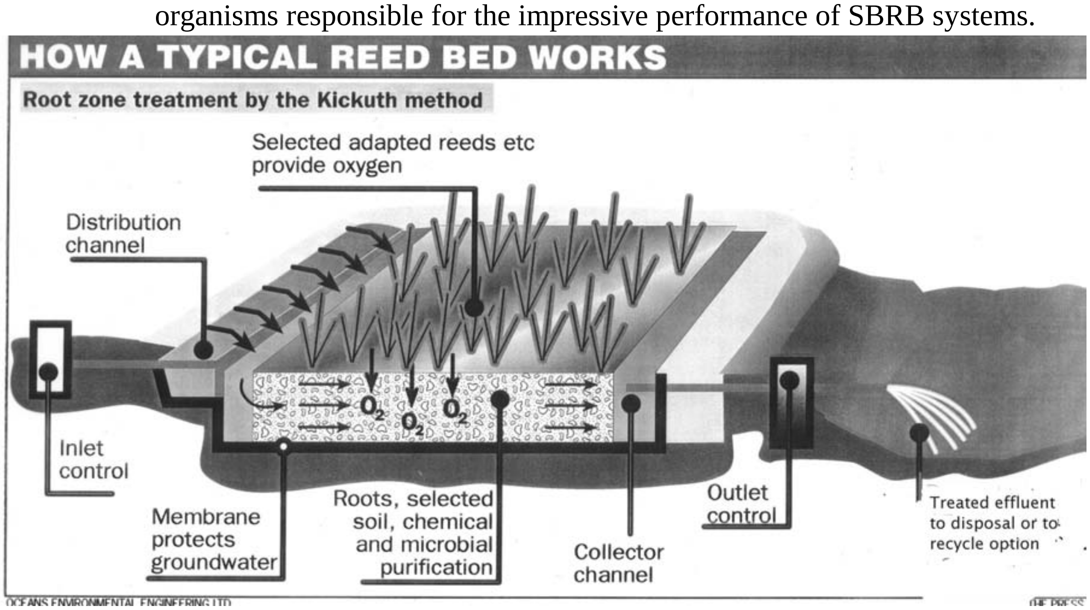


9.2 Industrial wastewater recycling/treatment with Soil Based Reed Beds (SBRB)

SBRB has been used widely throughout the world to effectively treat domestic wastewater, as well as a diverse range of highly contaminated industrial, chemical and agricultural effluents. SBRB is a soil based plant and micro-biological system in which the effluent moves through the soil fully below the reed bed surface.. This includes substantial reduction of nutrients (i.e. total nitrogen and phosphorus) as well as Biological Oxygen Demand (BOD), Suspended Solids (SS) and Faecal Coliforms (FC). SBRB systems now provide high performance, reliability, long life and very low running costs, as well as an environmentally friendly treatment solution.

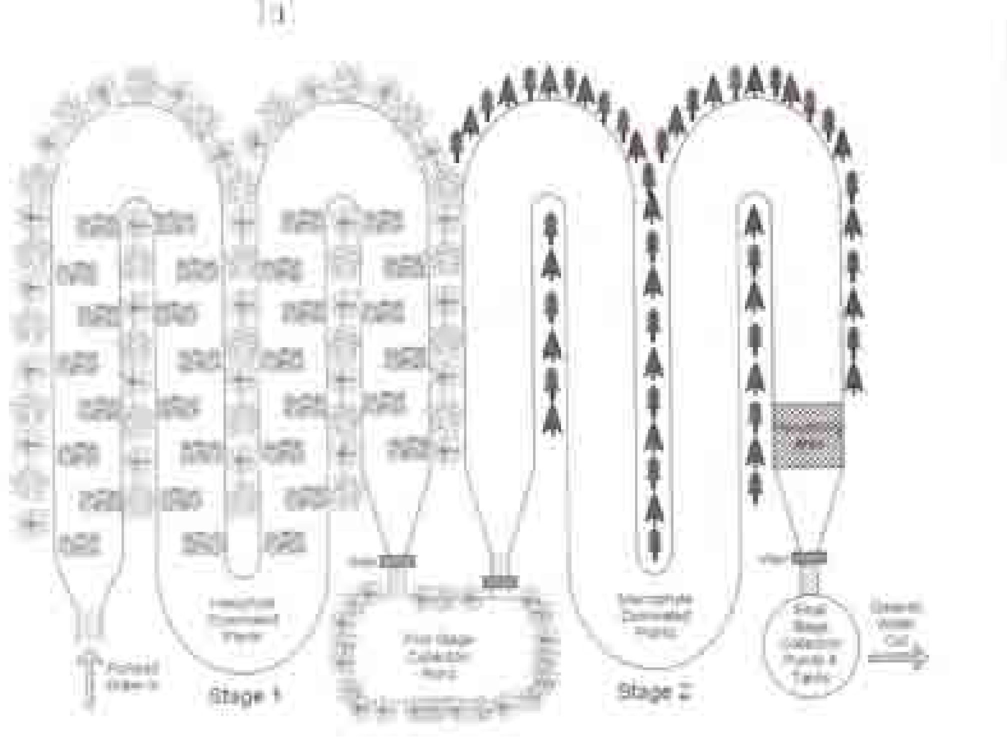
The SBRB system has three simple components, which interact in a complex manner to provide an ideal medium for wastewater treatment.

- **A shallow bed of soil** in which reeds are planted, contained by a waterproof membrane to prevent the wastewater leakage.
- **A suitable plant** which ideally should thrive under water logged conditions, tolerate high level of pollutants, high capacity of absorbing these pollutant and has high biomass production under these extremely adverse conditions.
- **Micro-organisms** (fungi and bacteria) in the planted soil and provide most of the treatment. The "reeds" root and rhizome systems bring air into the soil immediately surrounding them. Further away, the environment is anaerobic. These aerobic and anaerobic zones host an appropriate range of micro-organisms responsible for the impressive performance of SBRB systems.



9.2 Industrial wastewater recycling/treatment with flow through system.

In this system the first stage is treated with halophyte plants where wastewater is gravity fed to channels lined with vetiver plants and vetiver pontoons. The second stage the much less polluted water is polished up with macrophyte plants



9.3 Computer Modeling

In recent years**, c**omputer models have been increasingly considered as an essential tool for managing environmental systems. The complexity of wastewater management has made computer models instrumental in the planning and implementation of industrial wastewater disposal schemes. In Queensland, Australia, the Environmental Protection Authority has adopted MEDLI (Model for Effluent Disposal using Land Irrigation) as a basic model for industrial wastewater management.

The most significant development in VS use for wastewater disposal in recent years is that Vetiver was calibrated for use in MEDLI, for nutrient uptake and effluent irrigation (Veiritz, *et al*., 2003), (Truong, *et al*., 2003a), (Wagner, *et al*., 2003), (Smeal, *et al*., 2003).

10. ADVANTAGES OF VETIVER SYSTEM APPLICATION

Simplicity, low cost and low maintenance are the main advantages of VS over chemical and engineering methods for wastewater treatment.

10.1 Simplicity

Application of the Vetiver System is rather simple compared with other conventional methods. In addition appropriate initial design, only requires standard land preparation for planting and weed control in the establishment phase.

10.2 Low cost

Application of the Vetiver System in wastewater treatment costs a fraction of conventional methods such as chemical or mechanical treatment. Most of the cost lies in the planting material, with small amounts in fertiliser, herbicides and planting labour.

10.3 Minimal maintenance

When properly established, the VS requires practicaly no maintence to keep it functioning. Harvesting two or three time a year to export nutrients and to remove top growth for other usuages is all that needed. This is in sharp contrast to other means which need regular costly maintenance and a skilled operator, often an engineer, to operate efficiently.

11. CONCLUSION

The information presented above clearly demonstrates that the VS a very efficient and low cost method for treating effluent and leachate from both domestic and industrial sources. When properly designed and applied, the VS will certainly play a key role in minimising the impact of the imminent global clean water shortage.

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