VETIVER SYSTEM FOR WASTEWATER TREATMENT

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ABSTRACT

Clean water is becoming one of the most scarce and valuable resources in the twenty first century as its supply is finite and its traditional source is easily polluted by industries and population growth. Existing and traditional wastewater treatment methods are expensive and in most cases are either impractical or unsuitable for smaller communities and certain industries.

The Vetiver System was first developed for soil and water conservation purposes but tin the last six years its role has been extended into environmental protection field, particularly in the field of wastewater treatment and solid waste landfills. Research in Australia and China has shown that VS is a very effective method of treating polluted water, domestic effluent, industrial wastewater and landfill leachate.

1. Introduction

The Vetiver System (VS) is a new phyto-technology based on the use of vetiver grass (*Vetiveria zizaniodes* L.) for numerous environmental protection applications. VS has been developed from research, development and application programs around the world in the last 15 years. VS is now being used in over 40 countries with tropical and subtropical climates for various environmental protection purposes. This Technical Bulletin reports one of such applications.

Vetiver grass was first recognised in 1995 for having a "super absorbent" characteristics suitable for the disposal of leachate and effluent generated from landfill and wastewater treatment plants in Queensland, Australia. Chinese scientists later confirmed these results in 1997 and since then the Vetiver System has been used successfully for these purposes in Australia, China and Thailand (Truong, 2000).

Information presented in this Bulletin is results of R&D and demonstrations carried out in the last 10 years mostly in Australia, China and Thailand. In the last two years further research is being conducted in Australia with financial support from the Wallace Genetic Foundation of America through The Vetiver Network. The objectives of the current program are to:

- Quantify the effectiveness of the VS in reducing the nutrient load and volume of domestic and industrial effluents
- Develop a practical, effective, hygienic and low cost method of disposing effluent from small domestic sources
- Calibrate vetiver grass for application in computer modelling.

2. Special Characteristics of Vetiver Grass Suitable for Effluent Disposal

2.1 Morphological features

- Stiff and erect stems which can stand up to high velocity flows
- Thick growth forming 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

2.2 Physiological features

- Highly tolerant to adverse climatic conditions such as frost, heat wave, drought, flood and inundation
- Highly tolerant to adverse edaphic conditions such as high soil acidity and alkalinity, saline, sodic and magnesic, and Aluminium and Manganese toxicities.
- Highly tolerant to elevated levels of heavy metals such as Arsenic, Cadmium, Copper, Chromium, Lead, Mercury, Nickel, Selenium and Zinc. (Truong and Baker, 1998)

Table 1 summarises these special characteristics of vetiver grass.

Table 1: Tolerance Range of Vetiver in Australia and other Countries

Adverse Soil Conditions	Australia	Other Countries
Acidity	pH 3.0	pH 4.2 (with high level soluble aluminium)
Aluminium level (Al Sat. %)	Between 68% - 87%	80%-87%
Manganese level	> 578 $mgkg^{-1}$	
Alkalinity (highly sodic)	pH 9.5	pH 10.5
Salinity (50% yield reduction)	17.5 $mScm^{-1}$	
Salinity (survived)	47.5 $mScm^{-1}$	
Sodicity	48% (exchange Na)	
Magnesicity	2 400 $mgkg^{-1}$ (Mg)	
Heavy Metals		
Arsenic	100 - 250 $mgkg^{-1}$	
Cadmium	20 $mgkg^{-1}$	22 $mgkg^{-1}$
Copper	35 - 50 $mgkg^{-1}$	174 $mgkg^{-1}$
Chromium	200 - 600 $mgkg^{-1}$	
Nickel	50 - 100 $mgkg^{-1}$	
Mercury	> 6 $mgkg^{-1}$	
Lead	> 1 500 $mgkg^{-1}$	3 123 $mgkg^{-1}$
Selenium	> 74 $mgkg^{-1}$	
Zinc	>750 $mgkg^{-1}$	3 418 $mgkg^{-1}$
Latitude	15^0S - 37^0S	41^0N - 38^0S

Altitude		2 800m
Climate		
Annual Rainfall (mm)	450 - 4 000	250 - 5 000
Frost (ground temp.) (soil temperature)	-11^{0}C (12 ^{o}F)	-22^{0}C (7.6 ^{o}F) -10^{0}C (14 ^{o}F)
Heat wave	45^{0}C (113^{o}F)	60^{0}C (140^{o}F)
Drought (without effective rain)	15 months	
Fertiliser		
Vetiver can be established on very infertile soil	N and P (300 kg/ha DAP)	N and P, farm manure
Palatability	Dairy cows, cattle, horse, rabbits, sheep, kangaroo	Cows, cattle, goats, sheep, pigs, carp
Nutritional Value	N = 1.1 % P = 0.17% K = 2.2%	Crude protein 3.3% Crude fat 0.4% Crude fibre 7.1%

2.3 High water use rate

- Vetiver uses more water than other common wetland plants such as *Typha* spp, *Phragmites australis* and *Schoenoplectus validus*.
- Vetiver used approximately 7.5 times more water than Typha.
- Water use by vetiver grass was not affected by exposure to either Diuron or Atrazine herbicides at concentrations up to 2000 mg/L levels.
- Each three month old plant under wetland conditions used 0.6L of water a day over a period of 14 days.

3. Associated Research

3.1 Purification of Polluted Water

There are two ways of improving the quality of polluted water. One is to control the input of pollutants, particularly N and P, and organic pollutants to the water body, and another is to remove these substances from water.

In China research showed that vetiver can be used to remove high soluble N and P concentrations in polluted river water (Zheng *et al*. 1997).

Table 2 shows that the removal percentage of total P was 76-91% after 2-week growth, and more than 98% after 3 or 4 weeks. The removal rate was higher in river I water than in river II water. This might be because vetiver planted in river I water had more roots and thus stronger absorbability. The removal percentage of total N was a little less than that of total P. It was 34-45% after 1 or 2 weeks, and only 71-74% after 4 or 5 weeks. These indicate that the removal efficiency of P by vetiver is higher than that of N. Phosphorous is usually considered to be a key element in water eutrophication.

3.2 Control of Algal Growth in Rivers and Dams.

As soluble N and particularly P are usually considered to be key elements in water pollution, which normally leads to blue green algal bloom in inland waterways and lakes, the removal of these elements by vegetation is a most cost effective and environmental friendly method of controlling algal growth.

Research in China indicated that vetiver could remove dissolved nutrients and reduced algal growth within two days under experimental conditions (Anon, 1997). Therefore, VS can be used very effectively to control algal growth in water infested with blue-green algae. This can be achieved by planting vetiver on the edges of the streams or in the shallow parts of lakes where usually high concentrations of soluble N and P occurred. Alternatively vetiver can be grown hydroponically on floating platforms, which could be moved to the worst affected parts of the lake or pond. The advantages of this innovative floating platform method are that vetiver tops can be harvested easily for stock feed or mulch and vetiver roots can also be removed for essential oil production.

Table 2: Efficiency of vetiver in removing N and P from polluted river water

Growth time (week)	**1**	**2**	**3**	**4**	**5**
River water (I):					
Total P (mg/L)	0.30	0.083	0.007	0.009	
Removable (%)	**68.1**	**91.2**	**99.3**		
Total N (mg/L)	9.1			4.0	
Removable (%)	**34.1**			**71.0**	
River water (II):					
Total P (mg/L)		0.25	0.065	0.027	0.023
Removable (%)		**75.8**	**93.7**	**97.4**	**97.8**
Total N (mg/L)		5.76	4.40		2.71
Removable (%)		**45.1**	**58.1**		**74.2**

3.3 Control of Agrochemical Pollution

- *Sediment filter*

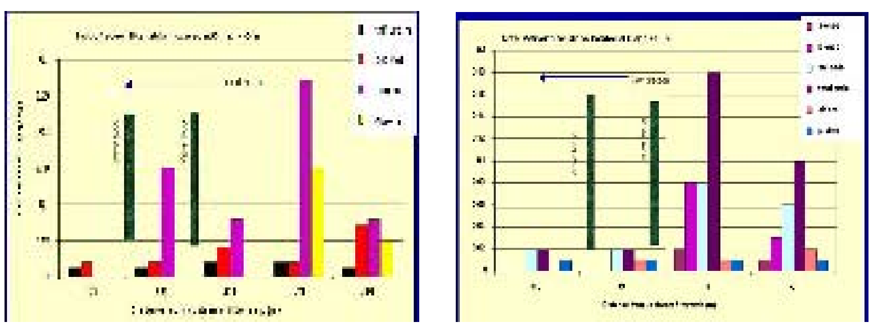
Herbicides and pesticides applied to farmlands are important for controlling weed and insect pests in crops but this practice, if not properly managed, can lead to serious off-site contamination of the surrounding environment. In particular, residues of these chemicals can adversely affect flora and fauna in downstream aquatic ecosystems.

In Australia research studies in sugar cane farms in north Queensland have shown that vetiver hedges were highly effective in trapping particulate-bound nutrients such as P and Ca. As expected, the hedges had little effect on soluble nutrients such as N and K. In the case of P, the reduction varied with the cultural practices employed, ranging from 26% to 69%. Similarly the largest amount of Ca trapped by the vetiver hedges ranged from 51% to 56%. These nutrients could be retained on site if vetiver hedges were established across drainage lines (Truong *et al*. 2000).

On cotton farms in central Queensland, vetiver hedges were also very effective in preventing herbicides (diuron, trifluralin, prometryn and fluometuron), pesticides [organochlorine (α, β and sulfate endosulfan) and organophosphate (chlorpyrifos, parathion and profenofos)] and nutrients (N, P and S) from leaving the farms. It was shown that during its first year growth, vetiver hedges were not very effective in trapping diuron, but fluometuron levels were greatly reduced. In the second year the vetiver hedge trapped 48% of diuron.

Soil samples collected at various distances upstream and downstream from the vetiver hedges grown on a cotton farm and analysed for selected organochlorine (α, β and sulfate endosulfan) and organophosphate (chlorpyrifos, parathion and profenofos). During its first year of growth the vetiver hedge trapped 86% of total endosulfan in the sediment of runoff water and 67% of chlorpyrifos. In the second year 65% of total endosulfan was trapped. These findings indicate that VS is highly effective at trapping the sediment bound chemicals: endosulfan and chlopyrifos, two of the more commonly used pesticides in cotton farming.

Similar to the results obtained in cane farms a significant amount of nutrients were trapped by the vetiver hedges. During the second year 73% of N in sediment was trapped as compared with 52% for P and 55% for S. (Truong *et al*. 2000).



Trapping herbicides (LH) and pesticides (RH) at a cotton farm in central Queensland

- *Wetlands*

Natural and constructed wetlands have been shown to be effective in reducing the amounts of some agricultural contaminants in runoff water. A glasshouse trial was undertaken in Australia to assess the potential for using vetiver grass and three wetland species in constructed wetlands, which receive agricultural runoff containing varying concentrations of two commonly used herbicides Atrazine and Diuron. Results showed that growth of vetiver was not adversely affected by application of Atrazine or Diuron at rates up to 2,000 $\mu g\ L^{-1}$. By contrast, growth in *Phragmites australis* was significantly reduced at the highest rate of application of both herbicides. Not only does vetiver establish and grow well under wetland conditions; it is also able to tolerate relatively high levels of Atrazine and Diuron (Cull *et al* 2000)

In Thailand it was reported that vetiver could decontaminate agrochemicals, especially pesticides and prevented them from accumulating in crops, polluting streams and other ecosystems. Some experiments were also carried out to determine the possibility of using vetiver grass to treat wastewater and it was found that vetiver could uptake significant amounts of N, P, K, Ca, Mg, Pb, Cd and Hg. Laboratory results also showed the ability of vetiver in absorbing heavy metals (Hengchaovanich, 2000).

4. Effluent Disposal

With the potential of removing very high quantities of N and P and very rapid growth, vetiver planting can be used both to reduce the volume and to remove nutrients in effluent from sewage, abattoirs, feedlots, piggeries and other intensive livestock industries. In Australia VS was used very successfully as an integral part of a wastewater purification program in removing nutrient from effluent from septic tanks.

4.1 Domestic effluent (black and grey waters)

- *Land irrigation system*

In 1995 an environmental consultant was looking for a fast growing plant for both erosion control as well as wastewater disposal at a holiday camp on the shore of a lake where the water supply of Brisbane is sourced. Secondary treated effluent was used to irrigate lawns and garden beds around the campsite. To ensure no surface or underground leaching reaching the lake, a very deep-rooted plant with high water use capacity was required. At this initial trial eight rows of vetiver were planted on a cut slope where the soil was very poor, to both stabilise the steep slope and to absorb runoff from irrigation runoff.

The result was completely unexpected as the first three rows of vetiver absorbed all the runoff, which previously ran down the slope. The absorption was so complete that while the first three rows had luxuriant growth, reaching almost 2m in eight months, the next five rows down the slope were less than 1m tall showing nutrient deficiency symptoms. This treatment has been very effective and stable in the last six years, the only management practice required is to cut and remove the top growth two or three times a year.

Eight rows of vetiver were planted to intercept surplus effluent discharge from a camp near Brisbane, Queensland, Australia

Eight months after planting, note the difference in growth between the top rows, which intercepted all the surplus effluent and leaving the lower rows deficient of water and nutrients.

Sixteen months after planting, note the poor growth and N deficient vetiver in the foreground as compared with excellent growth of plants from the top rows

Eighteen months after planting, a fully functional and sustainable effluent disposal system

Recently a project was carried out to demonstrate and to obtain quantitative data on the effect of VS in reducing the volume of effluent and also in improving its quality under field conditions. This project was conducted at the Beelarong Community Farm in Brisbane, Australia, where VS was used to dispose the discharge from a septic system on site.

Vetiver was selected after the failure of other plants including a variety of fast growing tropical grasses and trees, and crops such as sugar cane and banana to absorb the effluent discharge from the septic tank. The result to date has been very impressive. After five-month growth, vetiver was more than 2m tall and a stand of about 100 vetiver plants in an area less than $50m^2$ have completely dried up the effluent discharge.

The second phase of monitoring is now being carried out where nutrient load of discharge will be determined above and below the absorption area to demonstrate the efficiency of VS in decontaminating black water effluent (Hart, 2000b)

Vetiver was used to absorb effluent discharge from the septic system of this toilet at Beelarong Community demonstration centre at Morningside, Brisbane

Four months after planting, vetiver grew vigorously in effluent loaded with nitrogen and phosphorus.

This stand of vetiver absorbed all the effluent discharge from the toilet. Note the luxuriant growth, 5 months after planting

Six months after planting at an effluent disposal system with only 150 vetiver plants

- *Hydroponic system*

To determine the efficiency of vetiver grass in improving the quality of domestic effluent, a hydroponic trial was conducted using a mixture of black water (from toilet septic tank) and grey waters (from kitchen and bathroom). Results shown in Table 3 confirmed Chinese research in that 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.

Left: ***Sewage effluent infested with Blue-Green algae due to high Nitrate (100mg/L) and high Phosphate (10mg/L)***
Right***: Same effluent after 4 days treatment with vetiver, reducing N level to 6mg/L (94%) and P to 1mg/L (90%)***

Table 3: Changes in effluent quality after four day vetiver hydroponic treatment

Parameters	Measurements		% Changes
	Initial	Final	
Total Nitrogen	100 mg/L	6 mg/L	94
Total Phosphorus	10 mg/L	1 mg/L	90
Faecal coliforms	≥1600org / 100 mL	900 org / 100 mL	44
E coli	≥1600 org / 100 mL	140 org / 100 mL	91
Dissolved Oxygen	<1mg/L	8 mg/L	>800

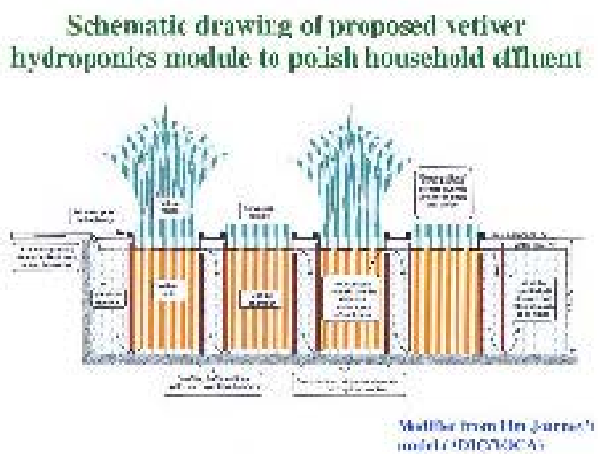
Electrical Conductivity	928uS/cm	468uS/cm	50
pH	7.26	5.98	
Water Use (4plants/drum)	1.1 L/day		

The presence of faecal coliform bacteria in aquatic environments indicates that the water has been contaminated with the faecal material of man or animals. *E. coli* is the most common faecal coliform. Environmental authorities often require faecal coliform or *E coli* tests on wastewater to indicate health risks from other disease producing bacteria or viruses that are likely to exist within the faecal material. Possible diseases include typhoid fever, viral and bacterial gastroenteritis and hepatitis A.

Due to the success of the preliminary trial a field trial is now being carried out at Jacaranda motel just north of Grafton in northern New South Wales, Australia. This motel offers accommodation in 25 units and approximately 24,000 litres of sewage effluent is pumped-out each week from two septic holding tanks and taken from site at a cost of approximately $A14 000 yearly. It is anticipated that under the VS the cost of establishment would be about $A15 000 with annual maintenance and monitoring costs of about $A2 000. It is expected that these are one-off costs to provide solution to the long-term disposal problem.

Set up of the field trial of the hydroponic system in 200L containers

Massive roots, 780mm long, on a platform suspended in effluent.



A possible model for vetiver modules for domestic effluent treatment.

4.2 Industrial Effluent – Plant nursery

The safe disposal of effluent from plant nurseries is a major problem for the industry, as leaching and runoff from intensive cultivation of young plants under both surface and drip fertigation provide a constant and elevated source of nutrients.

One of the largest flower nurseries near Brisbane faced with the problem of disposing a large volume of effluent runoff from the nursery floor and potting sheds. The problem was further exacerbated during the rainy season when the runoff volume often exceeded the capacity of the storage tanks. This effluent needs to be disposed off onsite, as under the strict environment law the nursery cannot discharge it into the sewer system.
Based on the use of sub-tropical pasture grasses, it was estimated that an area of at least 1500 square metres was needed to dispose the effluent generated by this nursery. As an initial trial, an area of 320 square metres was planted with vetiver at the density of 8 plants per square metre. Under the rich source of nutrient and plentiful supply of water, vetiver reached the full size of over 2 metres in height after 5 months and to the great delight of the nursery manager, this area of vetiver could absorb all the effluent generated by this nursery, even during the rainy season. Now in its third year, the VS is working in full efficiency and no further planting is needed. The only management required has been cutting and removing the top growth 2 or 3 times a year.

The plants in this very large nursery near Brisbane, are intensively irrigated and fertilized by overhead sprinklers, resulting in large volume of nutrient loaded effluent

An area of only 320m² is sufficient to dispose all the effluent generated from this nursery even during the wet season

4.3 Industrial Effluent- Piggery effluent (Liao X., 2 000)

China is the largest pig raising country in the world. In early 1996 China had 450 million pigs, accounting for 57.4% of the total in the world. In recent years pig raising changed from small farms to large scale concentrated production. 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 produced 100-150 ton of wastewater each day, which included pig manure collected from slotted floor, containing high nutrient loads.

Wetland is considered to be the most efficient means of reducing both the volume and the high nutrient load 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.

Table 4 shows the results of comprehensive evaluation on 12 species adaptable to pig farm wetland. 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.

Vetiver grass, *Polygonum hydropiper*, *Polygonum lapathifolium*, *Cyperus alternifolius* could grow under COD 2800 mg/L and NH3-N 390 mg/L; *Alocasia macrorrhiza, Cyperus exaltatus, Saururus chinensis, Juncellus serotinus*, elephant grass, *Calla palustris, Ranuneulus cantoniensis* could grow under COD 1300 mg/L and NH3-N 200 mg/L; *Scirpus triangulatus* could grow under COD 1040 mg/L and NH3-N 150.

Table 4: Evaluation of 12 species adaptation to wetland treatment of piggery effluent

Items	**Pollution tolerance**	**Biomass**	**Roots**	**View & admire**	**Easy to manage**	**Total**	**Remark**
Weight (%)	30	25	25	10	10	100	
Vetiveria zizanioides	80(24)*	80(20.0)	90(22.5)	80(8)	100(10)	84.5	2
Saururus chinensis	70(21)	50(12.5)	50(12.5)	60(6)	50(5)	57.0	7

Cyperus alternifolius	80(24)	100(25.0)	100(25.0)	100(10)	100(10)	94.0	1
Pennisetum purpureum	50(15)	85(21.0)	70(17.5)	80(8)	100(10)	71.5	4
Calla palustris	40(12)	50(12.5)	50(12.5)	50(5)	60(6)	48.0	10
Alocasia macrorrhiza	80(24)	75(18.8)	50(12.5)	50(5)	60(6)	66.3	6
Cyperus exaltatus	70(21)	80(20.0)	80(20.0)	80(8)	100(10)	79.0	3
Polygonum hydropiper	100(30)	25(6.3)	30(7.5)	50(5)	40(4)	52.8	8
Polygonum lapathifolium	90(27)	25(6.3)	30(7.5)	50(5)	40(4)	49.8	9
Juncellus serotinus	60(18)	80(20.0)	50(12.5)	80(8)	100(10)	68.5	5
Ranunculus cantoniensis	40(12)	30(7.5)	30(7.5)	60(6)	50(5)	38.0	12
Scirpus triangulatus	30(9)	40(10.0)	50(12.5)	80(8)	50(5)	44.5	11

* The first number is a mark out of 100 for a plant's single parameter (pollution tolerance, for example); the number inside the bracket is obtained by multiplying the mark by its percentage weighting which is given in the first row (for example, for vetiver: 80 x 30 % = 24).

Table 5 shows the efficiency of vetiver in removing COD, BOD, Ammonia and total P from the piggery effluent.

Table 5: Removing COD, BOD, Ammonia and P from piggery effluent.

Parameters	**Concentrations (mg/L)**	**Removal rates after 4 days (%)**
COD	825	64
BOD	500	68
Ammonia	130	20
Total Phosphorus	23	18

4.4 Industrial Effluent - Calibrating vetiver grass for computer modelling

MEDLI® (Model for Effluent Disposal using Land Irrigation) is a Windows® based computer model for designing and analysing effluent disposal systems for intensive rural industries, agri-industrial processors (e.g. abattoirs) and sewage treatment plants using land irrigation. It was developed jointly by the Australian Waste Management and Pollution Control, and the Queensland Departments of Natural Resources and Primary Industries (Gardner *et al*. 1996).

MEDLI models the effluent stream from its production in an enterprise through to the disposal area and predicts the fate of the water, nitrogen, phosphorus, and soluble salts. MEDLI is very flexible and can handle a wide range of industries such as piggeries, feedlots, abattoirs, sewage treatment plants, and dairy sheds, as well as any user-defined waste stream such as a food-processing factory.

To date MEDLI has been based on the use of common tropical and subtropical grasses and forage crops. As vetiver grass has clearly demonstrated its effectiveness in effluent disposal; it is therefore logical to use vetiver in the MEDLI model. However vetiver needs to be calibrated for MEDLI first. Research work is currently in progress to provide the special data set required.

5. Landfill Leachate Disposal

5.1 Australia

Leachate in Australian landfills (rubbish dumps) is often high in nitrogen compounds, total phosphorus, iron and manganese; has relatively high Electrical Conductivity at approximately 2 000 to 4000 μS/cm; and trace quantities of volatile organic compounds and heavy metals. Heavy metals detected commonly include Arsenic, Cadmium, Chromium, Nickel, Copper, Lead and Mercury, which are highly toxic to both plants and human. Stricter environmental laws and environmental protection licence conditions for Australian landfills now require landfill operators to prevent pollution of underlying and surrounding soil, groundwater and surface water, and particularly when concentrations of pollutants are likely to affect the health of humans, animals, plants and aquatic ecosystems (Hart and Tomlinson, 2000). For example, when heavy metal values exceed concentrations in soil as in Table 6, site works will be required to contain and treat the pollutants.

Australian authorities now commonly require a landfill to be encapsulated with a base liner and final cover to form what is commonly called a 'dry tomb'. Leachate generated in the waste falls to the sloping base liner of low permeable clay and or synthetic material and flows to a sump from which it is pumped or drained. The final cover is typically clay and topsoil and aims to seal out rainfall infiltration. The 'dry tomb' produces less leachate. However, 'bioreactor' landfill cell experiments where some controlled rain is allowed to infiltrate or leachate is recirculated, have shown pollutant concentrations reduce more quickly than in a 'dry tomb' and therefore reduce long term risks from leachate contamination. Vetiver grass can act as a corollary to the landfill bioreactor. With its long and matting roots, vetiver grass can be used to control the 'bioreactor' by containing and treating surface or underground egresses from the bioreactor system, either on the side slopes or at the toe of the landfill (Hart, 2000a; Hart, 2000c; Hart, 2001). This was done successfully as demonstrated in the following case study (Truong and Stone, 1996).

Leachate after rain on the side slope of an old landfill at Wellington Point near Brisbane, Queensland, Australia

This leachate runoff is highly contaminated with Chromium, Cadmium, Copper, Lead and Zinc. It will eventually discharge into the nearby sea.

Vetiver was planted to absorb this leachate. Twelve months after planting, excellent growth, unaffected by heavy metals contamination in the leachate

Within a year vetiver has completely stopped the leachate seepage

Vetiver was planted to absorb the leachate discharged from a landfill near Port Douglas, north Queensland, Australia.

When fully mature these rows of vetiver will prevent leachate running to the near by streams

Table 6: Investigation thresholds for contaminants in soils (ANZECC/NHMRC,1992)

Heavy Metals	Thresholds ($mgKg^{-1}$)	
	Environmental *	Health *
Antimony (Sb)	20	-
Arsenic (As)	20	100
Cadmium (Cd)	3	20
Chromium (Cr)	50	-
Copper (Cu)	60	-
Lead (Pb)	300	300
Manganese (Mn)	500	-
Mercury (Hg)	1	-
Nickel (Ni)	60	-
Tin (Sn)	50	-
Zinc (Zn)	200	-

*Maximum levels permitted, above which investigations are required.

The erosion at a 25-year-old landfill site at Wellington Point in Queensland, Australia was a great concern to the local community as this site is now surrounded by residential development. This landfill was capped with 1m of topsoil and successfully rehabilitated with local vegetation except for the side slopes (70% gradient) that remained bare of vegetation and were highly erodible. Soil testing found high levels of heavy metals, particularly Chromium and Cadmium (Table 7) and other toxic chemicals. Both water and wind erosion spread the contaminated materials to the surrounding areas and leachate runoff polluted adjacent ground and watercourses (Truong and Stone, 1996).

As vetiver grass is known to be highly tolerant to elevated levels of most of these heavy metals, the Redland Shire Council requested a trial to determine its suitability for use to control some serious problems at this site, particularly leachate runoff to local streams. Several leachate pools occurred on the side slope after heavy rains and leachate seepages are the permanent features of this landfill with colours ranging from rusty red to dark grey. The leachate eventually drained into small streams along the boundary of the landfill site. Table 8 shows that although the landfill is over 25 years old its leachate still contains very high levels of dissolved anions and cations. Heavy metals are relatively low.

Good establishment and growth were achieved and within 4 months vetiver was 0.3-0.4m tall and spreading. The same level of growth was noted on both the exposed landfill area and the less eroded area. There was no symptoms of toxicities and growth was as high as 1.5m ten months after planting and fully mature in 13 months, except for landfill gas emission areas.

For leachate control, vetiver was planted *en masse* (10 to 12 plants/m^2) at the toe of the slope where leachate appeared. Although both the landfill materials and the leachate were heavily contaminated (Tables 7 and 8), vetiver established easily and grew well with N and P application at planting. Leachate seepage was reduced substantially during the wet season and was eliminated during the dry season within 9 months. Fifteen months after planting vetiver eliminated the seepage even during the wet season.

Table 7: A typical heavy metal profile of the old landfill at Wellington Point.

Elements	Units	Sample Depth (cm)		
		0 - 10	20 - 30	40 - 50
pH	-	3.7	3.5	4.0
EC	$dmSm^{-1}$	2.75	2.38	1.9
Al	%	6.42	7.96	7.55
Na	%	0.34	0.33	0.35
Ti	%	0.82	1.16	1.09
As	$mgkg^{-1}$	9.9	9.4	11.0
Ba	$mgkg^{-1}$	180	170	190
Cd	$mgkg^{-1}$	5*	7*	6*
Co	$mgkg^{-1}$	16	23	23
Cl	$mgkg^{-1}$	20.45	20.30	18.60
Cr	$mgkg^{-1}$	190*	260*	210*
Cu	$mgkg^{-1}$	27	32	31
Fe	$mgkg^{-1}$	6.30	8.40	8.01
Mn	$mgkg^{-1}$	150	230	180
Ni	$mgkg^{-1}$	25	37	31
Pb	$mgkg^{-1}$	15	25	25
Sr	$mgkg^{-1}$	24	11	40
V	$mgkg^{-1}$	100	210	200
Zn	$mgkg^{-1}$	56	66	62

*****Value exceeds permitted level.

One important observation during the course of this trial was the effect of landfill gas emissions on vetiver grass growth from the landfill body. At spots where emissions occurred, mature vetiver plants turned chlorotic (pale yellow); however growth of young plant was considerably retarded but both mature and young plants did not die. When landfill gas emissions were no longer evident growth resumed normally.

5.2 China

The pollution caused from fresh garbage and its leachate on the environment is becoming an increasingly serious problem in Guangzhou City. Wastewater leached from the Likeng Landfill site in Guangzhou contained high concentrations of pollutants, well above the effluent limits, which could be harmful to flora and fauna in the surrounding environment (Xia *et al*. 2000).

Table 8: Chemical analyses of leachate from an old landfill at Wellington Point.

Analyses	Units	Sampling sites		
		1	2	3
pH	-	5.3	8.2	7.9
EC	uS/cm	980	6450	4860
Total	mg/L	492	4286	3610
dissol.ions	mg/L	130	845	1755
Total Hardness	mg/L	5.6	18	6.5
Na adsor. Ratio				
Cations	mg/L	24	100	365
Ca	mg/L	17	145	206
Mg	mg/L	138	1007	487
Na	mg/L	2.2	300	41
K	mg/L	1.4	0.2	3.8
Dissolved Fe				
Anions	mg/L	18	714	860
Bicarbonate	mg/L	ND	69	ND
Carbonate	mg/L	ND	53	629
Sulphate	mg/L	291	1705	1017
Chloride	mg/L	ND	193	0.9
Nitrate	mg/L	ND	0.1	0.3
Fluoride				
Heavy metals	mg/L	<0.025	<0.025	<0.025
As	mg/L	<0.010	<0.010	<0.010
Cd	mg/L	<0.010	0.011	<0.010
Co	mg/L	<0.010	<0.010	<0.010
Cr	mg/L	<0.010	0.015	<0.010
Cu	mg/L	0.12	<0.05	4.1
Mn	mg/L	<0.025	<0.025	<0.025
Mo	mg/L	<0.025	<0.025	0.028
Ni	mg/L	<0.010	<0.010	<0.010
Pb	mg/L	<0.050	<0.050	<0.050
Se	mg/L	<0.010	0.048	<0.010
Zn				

ND = Not detected

Of the four plant species investigated, common water hyacinth (*Eichhornia crassipes*) was killed in two types of leachate tested; Bahia grass (*Paspalum notatum*) could not survive in the high concentration leachate (HCL) and was severely damaged in the low concentration leachate (LCL); alligator weed (*Alternanthera philoxeroides*) was greatly affected in HCL, but produced a considerably large biomass in LCL. Among the four plant species tested vetiver grass was the least affected by both leachates. The tolerance of the four species to garbage leachate was ranked as vetiver > alligator weed > Bahia grass> water hyacinth.

Of the two species growing relatively well in leachates, alligator weed on the whole was superior to vetiver in purifying LCL, especially in removing total N and nitrate N; but the effects of vetiver in removing seven "pollutants" in HCL were much better than alligator weed. The removal of P and COD in LCL by vetiver was also much better than alligator weed. Of all seven pollutants measured, the removal of ammonia N by vetiver was most effective, at about 80% in HCL and nearly 90% in LCL. Vetiver showed a quite high removal rate for P, over 74%. This research showed that vetiver and alligator weed respectively treat HCL and LCL landfill leachate effectively (Tables 9&10).

It was concluded by Xia *et al*. (2000).

- Vetiver can be established and survives in hydroponic conditions.
- Vetiver has a high level of tolerance to polluted water.
- Vetiver is very effective in removing pollutant from landfill leachates, particularly N and P.
- However, vetiver cannot be established directly in leachate ponds, as it does not float as alligator weed; it needs a floating platform to grow on.
- Vetiver grows rapidly and has a huge biomass. To sustainably remove pollutants from leachates, vetiver shoots should be trimmed 2-3 times per year.

In Guangzhou, China, vetiver planted on a thin layer of topsoil on a fresh landfill site (Photo Credit: Xia Hanping)

One year after planting (Photo Credit: Xia Hanping)

Table 9: Efficiency of vetiver in removing pollutants from landfill leachates

Pollutants		High Concentration Leachate (mg/L)	Low Concentration Leachate (mg/L)
Total P	*Initial*	4.43	2.60
	After 66 days	1.33	0.91
Total N	*Initial*	1125.0	293.8
	After 66 days	232.2	84.8
Carbonate + Bicarbonate	*Initial*	1882.9	395.5
	After 66 days	365.5	162.0
COD	*Initial*	1120.1	246.0
	After 66 days	347.2	93.7
Chloride	*Initial*	1406.4	812
	After 66 days	1103	748

Table 10: Removal rates of pollutants from landfill leachates

Pollutants		High concentration Leachate	Low concentration Leachate
Total P	Removal (mg/pot)	7.63	4.66
	Reduction %	70.0	65.0
Total N	Removal (mg/pot)	232.1	255.4
	Reduction %	79.4	71.10
Carbonate + Bicarbonate	Reduction %	80.6	59.0
COD	Reduction %	69.0	61.9
Chloride	Removal (mg/pot)	321.9	207.8
	Reduction %	21.5	7.9

5.3 Thailand

At a major landfill at Kamphaengsaen, 90 km northwest of Bangkok, where 5000 tons of garbage is being dumped daily, a test section has been earmarked for the planting of vetiver. Planting was carried out in July 1999. After four months, it was observed that the plants were able to survive fairly well, despite the presence of leachate and toxicity normally expected of such a dumpsite. Field studies as well as parallel laboratory experiments are being conducted at Chulalongkorn and Kasetsart Universities using radio active and conventional techniques to assess its performance. The experiments are still ongoing, but it is anticipated that the outcome will reveal the practicality and effectiveness of vetiver grass for the remediation of landfills. As there are currently 50 landfills in Thailand, findings from this research will have positive repercussion on measures to overcome this problem now besetting many communities worldwide (Hengchaovanich, 2000).

Leachate control trial on a large landfill site near Bangkok, Thailand (Photo Credit: Diti Hengchaovanich)

Good vetiver growth 5 months after planting (Photo Credit: Diti Hengchaovanich)

6. Future Applications

Disposal of sewage effluent to streams, rivers and oceans is the traditional way of disposing effluent processed in domestic and industrial wastewater treatment plants. With an increasing awareness that water is a valuable resource, there is now a realisation that land disposal of treated effluent is more environmentally conscious and can have economic benefits if used for irrigation of golf courses and field crops such as sugar cane etc. These uses of reclaimed water are obvious solutions where an existing agricultural use or recreational area is available.

Vetiver on the other hand has far more potential given the variety of ways it can be used to treat and absorb domestic, agricultural and industrial effluents. It can be floated in final treatment ponds and be planted on their banks. Vetiver can be grown even on poor soil, irrigated with effluent and harvested for livestock. It can be used to establish constructed wetlands or to improve the phyto-treatment of effluent in natural wetlands, either small scale or large scale. Effluent can be treated hydroponically to an environmentally safe level by vetiver in containers before it is even released for irrigation. The following are some applications under investigations in Australia.

6.1 Control of Algal Bloom

Due to its superior absorption capacity of pollutants in wastewater, particularly N and P, investigations are underway in Australia to develop practical methods of control algal blooms in wastewater storage dams.

Water in this leachate pond was highly contaminated with Blue Green algae

Newly planted vetiver on this floating platform. A trial is being conducted to determine the planting density needed to decontaminate this pond.

6.1 Wetlands

Vetiver is a robust plant, structurally strong and tolerant of high effluent loadings. It has been demonstrated that vetiver can treat almost raw domestic effluent without having to be diluted. Perhaps its greatest large-scale application is in wetlands. Natural and constructed wetlands have been shown to be effective in reducing the amounts 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, involving microbiological transformations and physio-chemical processes such as 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):

- Its ability to tolerate flooded soil conditions making it ideal for use in ephemeral or permanent wetlands.

- Its dense stands 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).
- Its dense, finely structured root system can improve bed stability and nutrient uptake, and provide an environment that stimulates microbiological processes in the rhizosphere.
- Most importantly its sterility should minimise its potential for becoming an aquatic weed.

Vetiver in a wetland.

7. Conclusion

The information presented above clearly demonstrates that the Vetiver System is a very efficient and low cost method for treating effluent and leachate from both domestic and industrial sources.

In domestic situations worldwide, the potential of vetiver grass systems is enormous as a simple, hygienic and low cost means of treating human sewage whether it be in the single home, subsistence agriculture plot situation; on non-sewered small and large 'out of town' properties; or as an adjunct to current sewage treatment plants. Research has also verified vetiver's ability to treat landfill leachate and large-scale livestock and abattoir wastewater. Site-specific designs are being refined for vetiver grass planting expanse and medium, for wastewater system flows through the vetiver, and for monitoring total system effectiveness.

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BIODATA

Dr Paul Truong, Principal Scientist, Queensland Department of Natural Resources and Mines, has conducted a wide range of R&D on the application of the Vetiver System for environmental protection purposes, including mine rehabilitation and wastewater treatment in the last 10 years. In the last three years he has concentrated on the development of a low cost, efficient and hygienic method of disposal of human effluent and also large scale industrial wastewater.

Barbara Hart is the Principal Scientist of Codyhart Environmental Consulting Pty Ltd, she holds the Master degree in Environmental and Community Health. Barbara has wide experience in the management of solid waste landfills and other environmental issues associated with waste management, groundwater, surface water and gas monitoring, landfill leachate irrigation after working for several years as a Queensland Government Environmental Officer. Barbara is now an environmental consultant specialising in landfill monitoring and solid waste management. She is also an environmental researcher into groundwater monitoring techniques.

In conjunction with Dr Paul Truong, Barbara has been conducting research into hydroponic Vetiver System treatment of human effluent and landfill leachate. Other Vetiver System projects are in train to groundwater monitor the efficacy of vetiver planted on landfill slopes and human effluent absorption beds.