Hydroponic Vetiver Treatment of Post Septic Tank Effluent

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The Vetiver Network Award Winner

Abstract: A series of trials have been conducted to evaluate the efficacy of Vetiver growing under hydroponic conditions to treat motel effluent, which has been primary treated in septic tanks. Water quality results and management issues are of interest. The aim is to surface irrigate the motel gardens with the treated effluent in a sustainable way. This can be accomplished if excessive nitrogen does not seep through and contaminate groundwater, and if pathogen concentrations are almost minimal so as not to cause sickness for humans working or playing in the gardens sprayed with treated effluent. Results indicate that the best method trialled is effluent flow at 20 L/min through Vetiver roots, a method that is highly successful in reducing nitrogen concentrations. At an effluent flow rate of 20L/min, one square metre of long rooted hydroponic Vetiver can treat 30,000 mg total nitrogen in eight days, and with light excluded in the recirculation tank can treat 3,575 mg total phosphorus in eight days. Phosphorus reduction was not as successful but is often not an environmental issue if irrigated with no run-off. Pathogen content needs further testing to ascertain if sand filtering is necessary post hydroponic Vetiver treatment.

Key words: Vetiver, hydroponic, effluent, nitrogen, phosphorus, pathogens, irrigation

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1 INTRODUCTION

Trials using Vetiver in a contained system to treat motel effluent were motivated by two objectives: (1) to establish an effluent treatment system for a motel not connected to a city's sewage treatment system, and (2) to protect groundwater quality from any hidden percolation of highly concentrated wastewater.

1.1 Motel's present effluent management

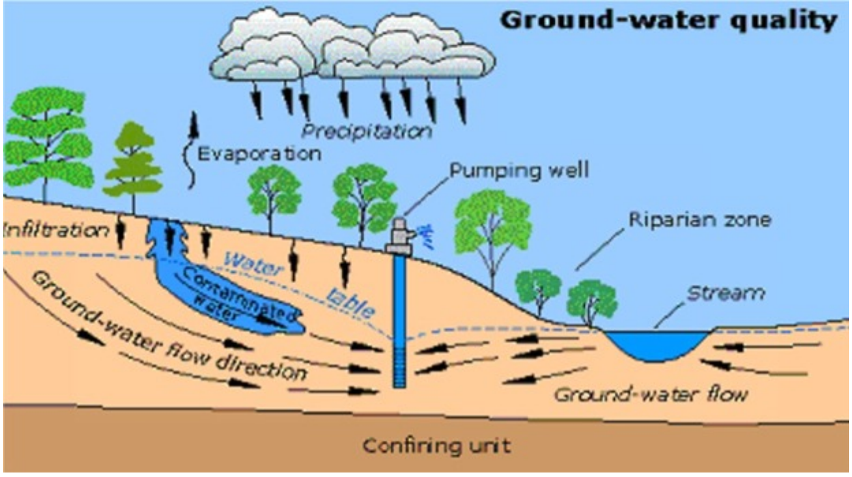
The Jacaranda Motor Lodge occupies a property of about 4 hectares on the outskirts of the city of Grafton in northern New South Wales, Australia. Due its isolated position away from the city, sewerage pipes for the city do not service the site. As a result, the motel relies on septic tanks to primary treat the effluent from the motel's 25 units and restaurant. Septic tanks are single or multiple chambered with an inlet pipe at one side that directs the incoming effluent vertically downwards towards the bottom of the tank. Settleable solids and partially decomposed sludge settle to the bottom of the tank where they are partially decomposed by anaerobic bacterial action. The settling also separates out clearer liquid which, when it reaches the outlet pipe exit level, overflows to holding tanks. Floating scum is also trapped inside the septic tank because the outlet pipe inlet is below the floating scum. Approximately 24,000 litres of effluent is pumped-out each week, and taken to a sewage treatment plant, at considerable cost to the motel owners.

The Grafton subtropical climate is suitable for vigorous Vetiver growth, and the Grafton City Council has given permission for the trialling of the hydroponic Vetiver treatment of effluent from the motel's effluent holding tanks.

1.2 Groundwater protection

Groundwater protection is often compromised because it is hidden from view, and its occurrence and movement is generally not understood. Groundwater needs to be protected from wastewater contamination (Figure 1). If the stream in Figure 1 was lowered, contaminated groundwater would seep into the stream and other surface waters such as rivers, lakes and dams.

Figure 1 Groundwater needs to be protected from wastewater contamination.



Source: U.S. Geological Survey (2003)

The Agriculture and Resource Management Council of Australia and New Zealand, and the Australian and New Zealand Environment and Conservation Council (ARMCANZ and ANZECC 1995) state that about 18% of total water used in Australia is groundwater. In the United States, 23% of total water used is groundwater (U.S. Geological Survey 2003). On-site effluent treatment systems are known to contaminate groundwater, the very groundwater that the same property owners might be extracting for drinking water, crop irrigation or stock watering purposes.

A major concern is nitrate (NO_3) contamination of groundwater from on-site effluent treatment. Groundwater nitrate values have increased from <1 NO_3-N mg/L to 14 NO_3-N mg/L (Rawlinson, 1994) in areas of Australia where septic tanks are used. Nitrates are soluble in groundwater, will travel considerable distances, are washed out into rivers (Andrews *et. al* 1997), and are a problem for humans and irrigated crops. When used in an infant's drinking water at NO_3-N ≥10mg/L, nitrate is changed into nitrite in the child's stomach and results in reduced oxygen transportation by the blood, and may even cause death. A nitrate concentration of NO_3-N <10 mg/L is required in many countries to protect drinking water quality, for example, as defined for Australia by the National Health and Medical Research Council (NHMRC and ARMCANZ 1996). Adults tolerate nitrate better, the recommended maximum being NO_3-N 23 mg/L (ANZECC 1992). Decreased crop yields and crop quality may result if long-term, total nitrogen in irrigation water is > 5 mg/L (ANZECC and ARMCANZ 2000).

Rawlinson (1994) reports that bacteria, on the other hand, are a localised concern from on-site domestic wastewater treatment, the degree of contamination depending on how quickly bacteria reach groundwater where they are more likely to survive and travel. Unsaturated soils filter the bacteria and impede their progress to saturated groundwater. Cogger (1988) in Rawlinson (1994) reports that in most studies of bacteria and virus movement, the majority were removed by 30 cm with almost complete removal by 60-120 cm. If the bacteria reach groundwater, the bacteria may travel up to 170 metres, as noted by Rawlinson (1994) concerning a study of *E. coli*, which are intestinal bacteria commonly used to indicate pollution of waters by humans and other animals. Toze *et al.* (2001) report removal times of 3 to 33 days for bacteria in groundwater.

If contained hydroponic treatment of domestic effluent using Vetiver is successful, it will provide greater assurance that underlying soil and groundwater are being protected. The trials also provide the opportunity to more reliably quantify Vetiver treatment effects because the effluent is fully contained and measurable, and soil properties cannot be confounding variables.

1.3 The Vetiver trials

Three vetiver trials have been undertaken to investigate how long it will take Vetiver to hydroponically treat effluent, and to note management issues that must be addressed if hydroponic Vetiver treatment is to be a viable alternative to land irrigation and wetland treatment of effluent.

2 LITERATURE REVIEW

For isolated places, on-site treatment of effluent is a necessity. Rawlinson (1994) reviewed the current types of on-site wastewater treatment systems that follow after a septic tank, namely: soil absorption systems, sand filters and aerobic systems. Irrigation systems may follow the latter two. Wetland systems are only briefly discussed but information is found in other literature references. Very little information is found in the available literature on hydroponic treatment of effluent.

2.1 Soil absorption systems

Beavers (2002) explains that even greywater (non-toilet effluent) irrigation to land may present health risks, degrade the soil and contaminate underlying groundwater:

- Access points to open tanks and ground ponding of effluent as stagnant pools provide a ready breeding ground for mosquitoes.
- Unless adequately treated, stored greywater allows *E. coli* to multiply 10 to 100 times during the first 48 hours of storage. Guidelines such as the Standards Australia/Standards New Zealand (2000) therefore state that for effluent to be spray irrigated, the effluent quality must reach secondary effluent standard, that is, 20 mg/L biochemical oxygen demand (BOD), 30 mg/L suspended solids (SS) and 10 org/100 mL *E. coli*. Disinfection of the effluent may be required if there is a layer of mulch covering the irrigation area or the groundwater table is known to be shallow in the area.
- Excessive watering of greywater on a restricted area may result in grey/green slime caused by the presence of soaps, shampoos, detergents and grease in the greywater, and allow run-off to stormwater waterways.

- Application of too much water of any kind can result in plant disease and soil degradation. A number of examples are given by Beavers (2002). Boron from laundry powders may cause leaf tip and margin burn, leaf cupping, chlorosis, branch dieback, premature leaf drop and reduced growth. Laundry powders, powdered detergents and soap contain ~80% sodium as filling which makes greywater quite alkaline (pH 8.0 – 9.2). Sodium gradually replaces calcium and magnesium on the surfaces of soil particles, making it sodic, which means that with too much sodium, the soil disperses when less saline water such as rain falls on it, clogging soil pores, forming a compacted layer at the surface, and causing erosion.

In comparison to Beavers' (2002) more general description that is most applicable to surface irrigation, Rawlinson (1994) explains dedicated, underground absorption systems such as evapo-transpiration beds, seepage pits, mounds and serial distribution systems. Although Rawlinson (1994) mentions groundwater contamination that may occur from seepage pits, there is no mention of the clogging problems that occur, or groundwater contamination that must occur with high loads.

2.2 Sand filters

Rawlinson (1994) explains that effluent is dosed onto a sand filter, drains through to a bottom layer of gravel, and then drains to the soil absorption system. The sand filter increases the absorption rate into the soil absorption system. The Victorian Environment Protection Authority (VIC EPA 1997) provides design specifications for a sand filter and Standards Australia/Standards New Zealand (2000) provides design specifications for a sand mound. Rawlinson (1994) also cites a newer type of septic system that seems to be merely a form of sand filter, two cells added after the septic tank containing red mud residue and sand. The results showed good reduction in phosphorus to <0.05 mg/L and faecal coliforms to <500 org/100mL.

2.3 Aerobic wastewater treatment systems

ANZECC and ARMCANZ (1996) suggest that an aerobic wastewater treatment system is secondary treatment because it reduces BOD, SS and pathogens, which is additional to primary treatment in a septic tank. Rawlinson (1994) explains the additional compartments and devices in an aerobic wastewater treatment system: a compartment for aeration using such devices as plastic media for trickling, rotators or submerged diffusers; a compartment for secondary settling and scum and sludge removal; a disinfection unit; and a pump for delivering effluent to the disposal area. However, results reported by Rawlinson (1994) of research by Beavers (1993) show that a simple sand mound provided better treatment than the more costly aerobic wastewater treatment system. Both the aerobic systems and the sand mound reduced faecal coliforms considerably. Nevertheless maximum treated values of 50 mg/L in both systems for total nitrogen and 12 mg/L and 10 mg/L respectively for total phosphorus are still unacceptably high.

2.4 Nitrogen and phosphorus removal

Nitrogen and phosphorus removal is the major difference brought about by tertiary treatment, although ANZECC and ARMCANZ (1996) also include further SS and pathogen reduction in tertiary treatment. ANZECC and ARMCANZ (1996) explain that tertiary treatments include detention in lagoons, further filtration and artificial wetland processes. For ponds, they suggest 20 days detention to reduce bacteria by 6 log units, and viruses by up to 5 log units, and a series of ponds to avoid short-circuiting and turbulence. However, VIC EPA (1997) suggests 30-day detention in a pond 2 metres deep for efficient reduction of bacteria in a well-oxidised effluent.

Rawlinson (1994) points out that Australian State guidelines for on-site effluent treatment do not include criteria for nitrogen and phosphorus removal, and as a consequence current designs do not remove nitrogen and phosphorus. However, there are some suggestions in the literature. Rawlinson (1994) mentions that a Wisconsin study found septic tank/peat filter, septic tank/recirculating sand filter, and a system that relies on separating kitchen and laundry wastes from toilet and shower wastes, had the greatest potential for nitrogen and phosphorus removal. Phosphorus removal is recommended to prevent potential eutrophication and algal blooms from runoff into surface waters (New South Wales Environment Protection Agency, NSW EPA 1995a). However, NSW EPA (1995a) states total phosphorus in the range 4 mg/L to 10 mg/L, as found in domestic effluent, is suitable for irrigation if properly managed. Further assurance is gained by testing the capacity of the soil and plants to uptake the phosphorus, and harvesting irrigated crops a number of times per year because this increases phosphorus uptake. Between 15% and 25% of applied nitrogen is lost to the atmosphere simply by irrigating secondary treated effluent, and nitrogen losses are generally lower in cold rather than warm climates (NSW EPA 1995a).

The performance of constructed wetlands is of interest as a comparison to hydroponic Vetiver treatment. Some conclusions from a Queensland Department of Natural Resources (QLD DNR 2000) study of ten constructed wetlands using Australian native plants for treating secondary effluent are as follows:

- Constructed wetlands are unable to produce an effluent similar to that produced by an advanced treatment technology. Initial concentrations and wetland performance varied considerably from wetland to wetland as shown from the following results (Table 1).
- If incoming effluent nitrogen is mainly nitrate and a low dissolved oxygen regime is maintained, nitrate removal is very efficient.
- Ammonia may increase when initial concentrations are 5-10 mg/L.
- COD is not a good indicator of wetland performance because the degradation products from wetland treatment may increase COD.
- Phosphorus is removed in the early period of wetland operation as the macrophytes become established. After establishment, poor removal performance, if any, can be expected.
- There were no ongoing mosquito problems. [Dale *et al.* (2001) believe this is due to predators eating the larvae.]
- Under most circumstances, at least one log removal of faecal coliform can be expected.

Table 1. Effectiveness of ten Queensland wetlands in treating N and P in effluent

	Initial concentrations	**Removal range**
Ammonia	0.75 mg/L to 23 mg/L	-36% to 100%
Total nitrogen	5.3 mg/L to 34.5 mg/L	26% to 97%
Total phosphorus	3.3 mg/L to 9 mg/L	-38% to 62%

NSW EPA (1995b) states that constructed wetlands are not a substitute for augmenting a sewage treatment plant. In addition, they suggest that wetlands should be designed in sections that have independent water level controls for independent servicing, and that sections should be sufficient in number to maintain treatment while other sections are serviced or their crops harvested.

2.5 Other hydroponic treatments

Ocean Arks International (2003) promote their "wastewater treatment restorers", a variety of floating structures fabricated from high-density polyethylene (HDPE) pipes. They may be floating islands, typically from 5 metres to 10 metres square, or of smaller construction to suit the situation, for example, Photo 1 shows the Baima sewage canal in southern China. However, their systems also require a hanging biofilm, aeration, and at least initial, if not ongoing addition of bacteria, fine powered minerals and trace elements to improve system functioning. Insufficient results are given to determine the efficacy of their system. In comparison, Vetiver pontoons at Toogoolawah Sewage Treatment Plant (Ash and Truong, 2003) function by merely floating vetiver on the effluent ponds (Photo 2).

Photo 1. Hydroponic treatment of sewage with other plants

Source: Ocean Arks International (2003)

Photo 2. Hydroponic treatment of sewage with Vetiver

Source: Ash and Truong (2003)

2.6 Literature review conclusion

Preceding literature information provides ideas that influence the approach and/or act as a comparison for the hydroponic Vetiver treatment trials. In particular, final effluent quality for spray-irrigation of the motel gardens can be defined. Vetiver hydroponic treatment needs:

- to filter the effluent to a level where there is minimal clogging;
- to reduce *E. coli* so that five samples taken half-hourly have a median value ≤10 org/100mL, and four out of five samples contain <20 org/100mL;
- to reduce total nitrogen ≤5 mg/L; and
- to reduce total phosphorus to the 4 – 10 mg/L range.

3 METHOD

A series of three trials were conducted from December 2000 to May 2003 to cover both summer and winter growing periods.

The first trial was conducted to gain an initial understanding of how long it takes Vetiver to treat effluent. Vetiver was floated in 20 litre drums and grown in effluent until the roots were the depth of the drum. Fresh effluent was poured into the drums at the start of the trial, which took four days to complete. Day water temperatures were very high at ≤37.7 °C.

Photo 3. Trial 1, hydroponic Vetiver treatment of effluent

The second trial was conducted to find the best growing medium for vetiver, how long it took Vetiver to treat effluent in colder conditions, and to note any other management problems. Media used ranged from still hydroponic with no supporting medium, recirculated hydroponic with no supporting medium, broken glass, river rocks, gravel and river sand. Vetiver was suspended in frames above the water level in 240 litre “wheelie” rubbish bins (Photo 4). For the no supporting media treatments, Vetiver was grown on top of the effluent saturated media. The trial was conducted from August to September 2002, when it was late winter to early spring, and water temperatures were mild at ≤20.0 °C.

Photo 4 Trial 2, hydroponic Vetiver treatment of effluent

In the third trial, a flow-through system (Photo 5) was used and it was conducted from February to May 2003. The aim was to find out if flow improved the treatment, and if so, what flow rate was the best. Effluent was pumped through a series of large bins that contained ~ 600 L of effluent and a trial prototype bin that contained 330 L of effluent. Separate trials were conducted using different flow conditions, over an eight-day period: no flow, and flow rates of 4 L/min, 10 L/min and 20 L/min.

Photo 5 Trial 3, hydroponic Vetiver treatment of effluent,
***left,* cut back at the start of the trial and *right*, vetiver growth after trial period**

Sampling for water quality analyses was conducted at the start of the trial, on some occasions during the trial, and at the end of the trial. Water quality analyses were conducted according to the needs of the analytical test: close to the bins at the time of sampling, in the motel room soon after sampling, on defrosted frozen samples requiring laboratory testing by the senior author using Hach reagents and colorimeter, or by a registered laboratory.

4 RESULTS AND DISCUSSION

Selected results are presented in Table 2 to give an overall understanding.

Table 2 Hydroponic Vetiver treatment of effluent - results

	Day	**T** °C	**EC** µS/cm	**pH** units	**DO** mg/L	**COD** mg/L	***E.coli*** org/100mL	**TC** mg/L	**NH_3** mg/L	**NO_x** mg/L	**N** mg/L	**P** mg/L	**Vol** L
Trial 1 (S)	0	25.9	928	7.26	0.82		≥1600		93	<0.01	99	10.0	14.0
20L drums	4	37.7	468	5.98	8.81		140		1	0.2	6	1.0	9.6
Trial 2 (W)	0	18.4	677	7.12	0.56				60	1.3	52	21.8	165.0
240L bins	14	19.5	410	6.40	3.66				6	0.3	6.5	19.3	111.3
Trial 3 (A)	0	24.6	759	7.18	0.21	248		144.5	48	0.02	46	5.9	1100
20 L/min	8	20.4	455	6.95	3.96	76		60.6	11	13	22	4.1	981

Notes: S = Summer; W = Winter; A = Autumn; Day 0 = commencement of trial; T = Temperature; EC = Electrical conductivity; DO = Dissolved oxygen; COD = Chemical oxygen demand; TC = Total carbon; NH_3 = Ammonia as a measure of ammonium ions as N; NO_x = (Nitrite + nitrate) as N; N = Total nitrogen; P = Total phosphorus; Vol = volume of effluent.

Given the area of hydroponic treatment for volume of water, Table 2 shows that Vetiver was particularly efficient in treating nitrogen compounds, electrical conductivity and dissolved oxygen. Hydroponic results in comparison to nutrient uptake rates of planted Vetiver, and other crops are shown in Table 3.

Table 3. Nutrient reductions hydroponic Vetiver, nutrient uptakes selected crops

Plant species	**Nitrogen** (kg/ha/year)	**Phosphorus** (kg/ha/year)
Trial 1 Vetiver hydroponic*	21,216	2,053
Trial 2 Vetiver hydroponic**	6,524	358
Trial 3 Vetiver hydroponic***	13,688	1,026
Vetiver pot trials (1)	2,040	153
Vetiver MEDLI model (2)	1200	100
Vetiver field trial (3)	1,142	149
Rhodes grass (4)	600	90
Kikuyu (4)	500	90
Green Panic (4))	430	70
Forage sorghum (4)	360	70
Sorghum + Ryegrass (4)	620	110
Bermuda grass (5)	280	30-35
Eucalypts trees (5)	90	15
Clover (5)	180	20
Rye grass (5)	200-280	60-80
Oats (5)	60	50
Lucerne (6)	269-504	20-39
Wheat (6)	23-208	3-27

* Still effluent, small size containers (25L)

** Still effluent, medium size containers (240L)

*** Flow through effluent at 20L/min, large size containers (600L)

Sources: 1- Wagner *et al.* (2003); 2- Vieritz *et al.* (2003); 3- Smeal *et al.* (2003); 4- Gardner pers. comm.(1995); 5- VIC EPA (1991); 6- NSW EPA 1995a.

It is obvious from Table 3 that hydroponic Vetiver has the highest nitrogen uptake compared with any other crop or pasture plants commonly grown in Australia. Under hydroponic conditions, Vetiver indeed has great potential as a reducer of nitrogen and phosphorus in effluent. At an effluent flow rate of 20L/min, one square metre of long rooted hydroponic Vetiver can treat 30,000 mg total nitrogen in eight days (Table 2, Trial 3), and it is interesting to note that with light excluded, the recirculation tank can treat 3,575 mg total phosphorus in eight days and only 2,250 mg (Table 2, Trial 3) when light is not excluded.

Other inferences from the three trials are as follows:

- In trial 1, nitrogen and phosphorus reduction is greater than in the other trials, because the plants were young, effluent was in small volume (10L), temperatures were very high and the surface areas were small (0.04m^2).
- Trial 2 resulted in the hydroponic Vetiver alternative, where the Vetiver just hangs from a frame and does not grow into any medium, being the most effective in treating the effluent. It also showed that Vetiver roots, in any saturated medium, stop growing in length at ~600mm from the top of the tillers.
- Trial 3 results are probably the best basis for future work. The plants were approximately two years old and had become accustomed to hydroponic conditions. Recirculation at 20

L/ min doubles the reduction in nitrogen and phosphorus of trial 2. However, a considerable portion of the nitrogen is oxygenated to nitrite and nitrate, in comparison to the previous still or minimal recirculation trials in which nitrogen remained as ammonia.

- Vetiver oxygenates the effluent, either with pumped flow or without it.
- Vetiver reduces salinity and carbon content of effluent, and reduces chemical oxygen demand.
- Vetiver acts as a canopy in heavy rainfall, greatly reducing the volume of rainwater falling into the container.
- Hydroponic Vetiver roots act as a filter (Photos 6); the roots trap sediment and much sediment falls to the bottom of the container. Photos 7 shows the cleansing effect of hydroponic vetiver.
- Problems encountered included mosquitos, and devising and building the flow system. Mosquitos are likely to be eliminated by preventing larvae entering the hydroponic Vetiver system and growing Vetiver roots through mosquito screen.
- Further testing is required in regard to *E. coli*. Testing was hampered by the *E. coli* maximum holding time of 24 hours before analysis.

Photo 6. Vetiver roots trap and filter.

Photo 7. Vetiver filtered effluent, L to R, tap water, Vetiver treated effluent, untreated effluent

5 MAJOR OUTCOME

The major outcome of this series of hydroponic trials is an estimate of the area of hydroponic Vetiver needed to treat the motel effluent:

Basic data:

Pre-treatment N and P data of Trial 3 (20L/min flow rate): 50 mg/L N and 5.9 mg/L P.
Reduction goal: 5 mg/L N and <10mg/L P.
Therefore reduction rates required: 45 mg/L N and 0 mg/L P.
Maximum possible peak daily flow = 6,750 L/day
[25 rooms x 1.5 guests @ daily flow of 180 L (VIC EPA 1997) = 6,750 L/day].

Using trial 3 results:

Reduction rate N: 3.75 $g/m^2/day$ (from 13,688 kg/ha/yr)

Reduction rate P: 0.28 $g/m^2/day$ (from 1,026 kg/ha/yr)

Calculation:

Only an N reduction calculation is necessary:

45 mg/L x 6,750 L = 303,750 mg N = 300 g N total reduction required each day

Therefore to reduce 300 g N @ 3.75 $g/m^2/day$ N reduction,
requires 80 m^2 of hydroponic Vetiver.

6 CONCLUSION

The trials reported in this paper indicate that on-site hydroponic Vetiver treatment of domestic effluent has the potential to be far more effective than other on-site systems, and that hydroponic Vetiver reduces considerably more nitrogen and phosphorus than other plants. The added bonus is that containment of the effluent to conduct hydroponic Vetiver treatment prevents effluent contaminating groundwater.

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8 REFERENCES

Andrews JE, Brimblecombe P, Jickells TD and Liss PS. 1996. An Introduction to Environmental Chemistry. Blackwell Science, Oxford, London.

ANZECC. 1992. Australian Water Quality Guidelines for Fresh and Marine Waters. Commonwealth of Australia, ANZECC, Canberra.

ANZECC and ARMCANZ. 1996. National water quality management strategy, draft guidelines for sewerage systems use of reclaimed water. Commonwealth of Australia, ANZECC and ARMCANZ, Canberra.

ANZECC and ARMCANZ. 2000. Australian and New Zealand Guidelines for Fresh and Marine Water Quality 2000. Commonwealth of Australia, ANZECC and ARMCANZ, Canberra.

ARMCANZ and ANZECC. 1995. Guidelines for groundwater protection in Australia. Commonwealth of Australia, ARMCANZ and ANZECC, Canberrra.

Ash R and Truong P. 2003. The use of Vetiver grass for sewage treatment in Australia. Proc. Third International Vetiver Conference, Guangzhou, China, October 2003.

Beavers P. 2002. On-site sewerage facilities - guidelines for the use and disposal of greywater in unsewered areas, draft for comment. Queensland Government, Department of Natural Resources and Mines, Brisbane.

Beavers P. 1993. Planning and Site Evaluation: The key to improved on-site wastewater disposal. Proc. Water Conservation and Reuse. Australian Water and Wastewater Association, Caloundra, Queensland.

Cogger C. 1988. On-site septic systems: the risk of groundwater contamination. Journal of Environmental Health, **51**(1): 12-16.

Dale PER, Greenway M and Chapman HF. 2001. Constructed wetlands for wastewater treatment and mosquito borne diseases in Queensland, Australia. In: Arbovirus Research in Australia, **8**, 109-116.

NHMRC and ARMCANZ. 1996. Australian drinking water guidelines. Commonwealth of Australia, NHMRC and ARMCANZ, Canberra. [on line] URL: http://www.nhmrc.gov.au/publications/synopses/eh19syn.htm

NSW EPA. 1995a. The utilisation of treated effluent by irrigation. New South Wales State Government, Environment Protection Authority, Sydney.

NSW EPA. 1995b. Wetlands for treating wastewater. New South Wales State Government, Environment Protection Authority, Sydney.

Ocean Arks International. 2003. Restorer technology. Ocean Arks International, Burlington, VT U.S.A. [on line] URL: http://www.oceanarks.org/restorer/indepth/

QLD DNR. 2000. Guidelines for using free water surface constructed wetlands to treat municipal sewage. Queensland Government, Department of Natural Resources, Brisbane.

Rawlinson L. 1994. Review of on-site wastewater systems. Environment Protection Authority New South Wales, Southern Tablelands Region, Sydney.

Smeal C, Hackett M and Truong P. 2003. Vetiver system for industrial wastewater treatment in Queensland, Australia. Proc. Third International Vetiver Conference, Guangzhou, China, October 2003.

Standards Australia/Standards New Zealand. 2000. AS/NZS 1547:2000, On-site domestic wastewater management. Standards Australia/Standards New Zealand, Sydney and Wellington.

Toze S, Dillon P, Pavelic P, Nicholson B and Gilbert M. 2001. Aquifer Storage and Recovery: Removal of Contaminants from Stored Waters. In: Water, **28**(7).

U.S. Geological Survey. 2003. Water science for schools. United States Government, Department of the Interior, Geological Survey, Washington DC.
[on line] URL: http://ga.water.usgs.gov/edu/

VIC EPA. 1997. Code of practice for small wastewater treatment plants. State Government of Victoria, Environment Protection Authority, Melbourne.

VIC EPA. 1997. Guidelines for wastewater irrigation. State Government of Victoria, Environment Protection Authority, Melbourne.

Vieritz, A., Truong, P., Gardner, T. and Smeal, C. 2003. Modelling Monto vetiver growth and nutrient uptake for effluent irrigation schemes. Proc. Third International Vetiver Conference, Guangzhou, China, October 2003.

Wagner S, Truong P, Vieritz A and Smeal C. 2003. Response of Vetiver Grass to Extreme Nitrogen and Phosphorus Supply. Proc. Third International Vetiver Conference, Guangzhou, China, October 2003.

A brief introduction to the first author

Barbara Hart, a groundwater monitoring specialist, is a director of CodyHart Environmental, a Gold Coast, Australia, environmental monitoring and management company specialising in landfill environmental monitoring. Ron Cody, the second author, is a director of the same company. In collaboration with Dr. Paul Truong, Ron and Barbara have conducted the research for this paper at the motel at which they often stay when engaged in their environmental monitoring work in the Grafton area of northern New South Wales, Australia. More information about CodyHart Environmental is available on our company website: www.codyhart.com.au