APPLICATION OF VETIVER GRASS IN SOIL BASED REED BEDS FOR EFFLUENT TREATMENT AT GELITA APA, AUSTRALIA

C. Smeal[1], P. Truong[2], J. Biala[3] and A. Butler[4]
[1] Gelita APA, Beaudesert 4285, Australia
cameron.smeal@gelita.com
[2]Veticon Consulting, 23 Kimba St, Chapel Hill, Brisbane 4069, Australia
truong@uqconnect.net
[3] The Organic Force, PO Box 74, Wynnum 4178, Australia
biala@optusnet.com.au
[4] Griffith University, Nathan, Australia
amanda.butler@student.gu.edu.au

ABSTRACT

Constructed wetlands using surface flow systems and floating aquatics have been used with success for the treatment of light load effluent. However heavy load wastewater has generally been treated through the use of subsurface flow reed beds, particularly the Soil Based Reed Bed (SBRB).

SBRB has been used widely throughout the world to effectively treat domestic wastewater, as well as a diverse range of highly contaminated industrial and agricultural effluents. A sub-surface flow soil based reed bed is a combination of three interdependent elements: the growing media, the plants and the micro-organisms. In this system the wastewater comes into contact with a wide range of microorganisms that occur in high densities on the surface of the growing media and around the plant roots. Systems constructed correctly from these three components offer sustainable long term treatment capabilities. Usually, this results in substantial reduction of nutrients (N and P) as well as other characteristics that determine water quality, such as Biological Oxygen Demand (BOD), Suspended Solids (SS) and Faecal Coliforms (FC). However, nitrogen removal through reeds that are commonly used (e.g. *Phragmites*) has not always been satisfactory.

GELITA Australia manufactures food grade gelatine from cattle hide, and in doing so generates 1.3 ML/day of effluent high in nitrogen (ammonia). While interested in using biological systems for effluent purification, GELITA beliefs that only plants with a high nitrogen uptake capacity will be able to reduce the nitrogen load in their wastewater to an acceptable level. Consequently, a plant was needed which thrives in water logged conditions, tolerates high level of pollutants, has a high capacity of absorbing these pollutants, particularly nitrogen and has also high biomass production under these extremely adverse conditions. Vetiver grass has all these qualities and holds considerable promise for use in soil based reed beds where high nutrient loads need to be removed.

GELITA Australia has initiated field research in order to:

- demonstrate the suitability of vetiver grass for use in the SBRB system to treat nitrogen rich industrial effluent;
- use the research findings in order to develop and establish a SBRB system that

is capable of purifying GELITA's wastewater to a satisfactory level;
- develop a SBRB system using vetiver grass suitable for Australia and world wide.

Keywords: Soil Based Reed Beds, pollution, effluent disposal, wter recucling

1.0 INTRODUCTION

Constructed wetlands using Horizontal Flow (HFW) and vertical Flow (VFW) systems and aquatic plants have been used with success for the treatment both industrial and domestic effluent. These wetlands are generally referred to as "reed beds" because they are often planted with reeds.

Horizontal Flow Reed Beds treat the water at a lower cost than conventional mechanical technology in capital and operating cost terms (Cooper *et al*. 1996). They also claim the system has the ability to 'purify water by removing organic matter (BOD) and oxidising ammonia, reducing nitrate and removing phosphorus.' HFW have been used with success for the treatment of light load effluent. However heavy load wastewater has generally been treated through the use of subsurface flow reed beds, particularly the Soil Based Reed Bed (SBRB).

Using the sub-surface flow system the wastewater comes into contact with the wide range of microorganisms that occur in high densities on the surface of the growing media and around the plant roots. Where fine particle size media are used (soils and fine sands), the number of micro-organisms is very significant. Additionally in the soil based system the inherent reactivity of the clay particles and humic particles within the matrix can be exploited as a measurable contributor to the treatment process. The common Reed Beds system uses gravel for growing medium, but some others utilise specially treated growing media, which can be fairly expensive ($100/ton).

Over the last twenty years the use of the system has progressed to encompass the installation of full scale plants for the treatment of waste waters from a very wide range of industries, particularly the food producing industry.

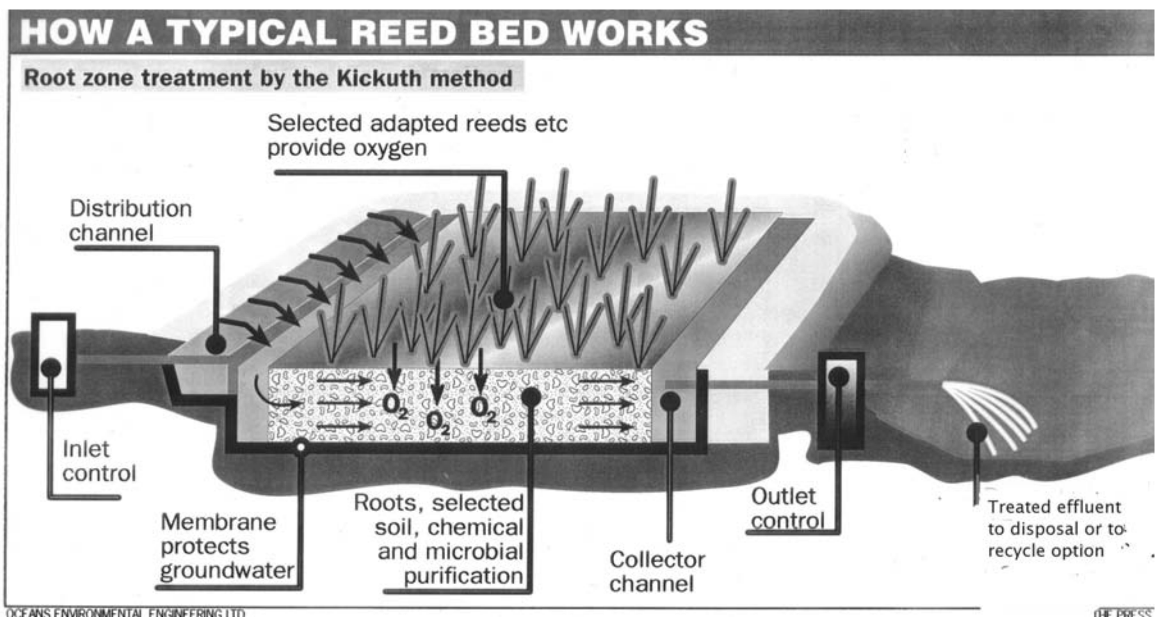
2.0 SOIL BASED REED BEDS

SBRBs have 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. The Reed Beds system described here is a soil based plant and micro-biological system in which the effluent moves through the soil fully below the Reed Beds surface. This wastewater treatment approach was originally developed in Germany over 30 years ago. SBRB systems have since been developed and refined through hundreds of successful applications around the world. 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. The treatment involves:

- **A shallow bed of soil** (between 0.5 and 1.5m deep) 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 soil which 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.

Systems constructed correctly from these three components offer sustainable long term treatment capabilities.



2.2 The Medium in SBRB

The types of medium used in the soil based reed bed is a vital and influential component to the treatment process. Removal of heavy metals present in the wastewater is done through a range of complicated chemical reactions and the soil minerals vastly influence the displacement of metal ions, phosphate and also sulphate. Various soils each have their own physical and chemical properties that advantage and disadvantage the treatment of wastewater in the SBRB system. For example, soils that contain clay particles and humic materials use these constituents to capture chemicals (CIWEM 2003). Furthermore clay soils tend to have a higher organic content and therefore are more microbiologically active then sandy or gravel media. However generally they have a very low hydraulic conductivity, which can result in ponding of the wastewater. The low hydraulic conductivity will also mean that the amount of wastewater that can be put through the system is limited. Clay soils tend to expand and retain water for this reason plants may have difficulty establishing and penetrating their root system into soil based reed bed.

A higher hydraulic conductivity is expected in gravel than clay. Findlater *et al* (1990) claims plants may have difficulty in deep rooting through the saturated zone of the gravel and gravel media contains fewer micro-organisms when compared to soil. This implies that the gravel SBRB may not be as effective in treating the wastewater compared to the other SBRBs.

2.3 Plants in SBRB

Plants within the soil based reed bed are the second major component for the treatment process. The type of reed chosen will vastly influence the efficiency and quality of wastewater. Plants provide an environment for microbes to live, they oxygenate the wastewater, providing nutrients for the microbes to survive, they stabilise the soil and they also partake in the reduction of nutrients. It has also been claimed that the root systems of plants create channels within the bed for water flow (CIWEM 2003). In a natural wetland system their main function is to photosynthetically generate organic carbon.

As stated above the plants commonly have active microbial sites within their rhizosphere. Most plants also have the ability to release oxygen through their root systems allowing them to survive in anaerobic conditions. This acts also as a survival mechanism for plants as it reduces the risk of toxicity by oxidising reduced compounds (Wallace 2002).The oxygen surrounding the root system also enables aerobic microbes to survive in fairly anaerobic environments (Wallace 2002). The reeds also assist in biological stabilisation over time as they contain lignin and humic acids present in the biomass (JTE 2006).

Plants require both nitrogen and phosphorus for growth. Usually however a plants intake of nitrogen and phosphorus is usually in the ratio of 10:1, respectively, under optimum conditions. Wallace (2002) states that if the plants are harvested the maximum uptake of nitrogen from the system by plants would only account for around 10 per cent. The plants work indirectly as well as directly to improve the nutrient removal in wastewater. Through evapo-transpiration alone plants can uptake 20 per cent of the wastewater in the SBRB system (JTE 2006).

2.3 Micro-organisms in SBRB

The microbial flora and fauna (such as fungi, algae, bryophytes and aquatic invertebrates) are considered as one of the most important constituents of the reed bed wastewater treatment. Evidence has shown microorganisms have an ability to also reduce synthetic fractious chemicals such as pesticides and chlorinated hydrocarbons (Crown 2006). Hatano *et al* (1993) agree that microorganisms present in the SBRB are vital for treating contaminants in wastewater. The majority of wastewater treatment by microbial activity occurs on sediment particles in the reed bed system. Microorganisms effectively work to degrade and mineralise chemicals present in wastewater (CIWEM 2003). Microbes are found in reed beds attached to substrate surfaces and plant roots (Liehr 1999). Liehr (1999) also claims aerobic environments commonly contain anaerobic microsites.

Population sizes of microbes both aerobic and anaeobic is dependent on three variables including nutrients available, temperature and available oxygen (Hatano *et al* 1993). Claims made by Liehr (1999) state that phosphorous is an essential nutrient for microbial biomass and therefore can limit growth. Hatano *et al* (1993) observed that microbial populations did vary with temperature and that the populations were significantly higher in the rhizosphere of the plants then on the gravel media used. Furthermore the dominant population of microbe that was recorded was bacteria.

Die-off, filtration, sedimentation, entrapment, predation, radiation, desiccation, chlorination and adsorption are all process that can occur in wetland and essentially remove microorganisms.

2.4 Nitrogen and Phosphorus Treatment Processes in SBRB

Nitrogen is removed through the processes of ammonification, nitrification and then denitrification, also through plant uptake and finally through ammonia volatilisation (Wallace, 2002, Brix, 1993). Envirowise (2006) advises that reed beds have the ability to nitrify and denitrify if they are designed accordingly.

The denitrification process produces nitrogen gas (N_2) as a by-product. Nitrogen is removed from the system due to the nitrogen gas being released into the atmosphere (Wallace, 2002). The breakdown of organic matter in the wastewater causes organic nitrogen to be converted to ammonium (NH_4^+). The cation exchange sites within the soil are attracted to the ammonia's positive charge ultimately causing the ammonia to become immobile in the soil profile (Wallace, 2002)

The nitrogen cycle continues as nitrification occurs by bacterial oxidation of the ammonium to the nitrogen form of nitrate (NO_3^-). This can only occur in aerobic conditions as the bacteria use oxygen from the surrounding environment to convert the ammonium. Unlike ammonia nitrate is very mobile in soils and often leaches down into ground water (Wallace, 2002).

The removal of phosphorus can be achieved through soil adsorption, complexation and precipitation reaction with aluminium, iron, calcium and clay minerals in the media and also through plant uptake (Brix 1993 and Chervek 2005). Sand and fine river gravel both contain iron and aluminium oxides so they are often used to remove phosphorus from wastewater (Chervek 2005). Brix (1993) claims that like nitrogen four main constituents, ie the loading rate, type of substrate and the wastewater type and chemical make-up, will determine the removal of phosphorus. Brix (1993) then explains the process of phosphorous removal can be enhanced through batch flooding and drying of the reed bed system. Pathogen removal in SBRB systems as describes by Brix (1993) advises that removal occurs through sedimentation, filtration, natural die-off, UV radiation and the excretion of antibiotics from macrophytes.

3.0 WHY VETIVER GRASS INSTEAD OF PHRAGMITES

From the above it is clear that plants used for SBRB should have an extensive root system to penetrate down to the base of the soil to ensure the system is properly aerated by the roots. The most commonly used plant for Reed Beds system is *Phragmites* sp and in Australia *Phragmites australis*, which is a common wetland plant, and is also a major weedy pest in all wetlands and waterways in Queensland due to its prolific seeding habit. In addition *Phragmites australis* has:

- A relatively shallow root system, typical feature of wetland plants
- A slow recovery growth after harvesting as it relies on the growth of new shoots from rhizomes and seeds instead of the old shoots.

Whereas Vetiver grass *(Vetiveria zizanioides)*:

- Thrives under water logged conditions,
- Tolerant to high level of pollutants, including heavy metals and nutrients particularly N and P (Kong *et al*. 2006)
- Has high capacity of absorbing these pollutants: 1 140kgN/ha/year; 150kgP/ha/year, as compared with Rhodes grass 600kg/ha/year and 90kg/ha/year, Kikuyu 500kg/ha/year and 90kg/ha/year, forage sorghum 360kg/ha/year and 70kg/ha/year, respectively (Truong and Smeal (2003).
- Grows well under extremely adverse conditions such high salinity, high acidity and alkalinity and sodicity (Truong and Baker, 1998).
- Has a prolific and deep root system with Shoot- Root ratio of about 1:1, reaching 4m deep under dry land conditions.
- Has high potential biomass production under nutrient rich condition such as effluent, 132tons/ha/year with 3 monthly harvests (Truong and Smeal (2003).
- Has higher water use rate than, 7.5 times higher than Typha under wetland conditions.
- Is sterile and producing no seeds therefore no weed potential
- Can be easily eradicated by uprooting or glyphosate spray

4.0 VETIVER GRASS IN REED BEDS

Summerfelt *et al* (1999) used vetiver grass for both HFW and VFW in a study for the removal and stabilization of aquaculture sludge. Vetiver was selected over other aquatic species because it is tolerant of a wide range of environmental conditions, and when planted as narrow hedges, the dense vetiver shoots act as a barrier, allowing more time for water to infiltrate through the soil. In addition Vetiver also has an extensive and deeply growing root system that would help maintains the bed's hydraulic conductivity and contributes to oxygen transport into the bed according to these authors.

Results indicated that with vetiver planting, sludge removal and stabilization occurred within both wetland types. The VFW and HFW cells, respectively, removed 98 and 96% TSS, 91 and 72% total COD, and 81 and 30% dissolved COD. Because little dissolved COD was expected to be removed by physical mechanisms, the increased removal of dissolved COD within the VFW cells was likely due to better anaerobic digestion occurring within the sand and gravel layers of the VFW cells**.** Both wetland types removed most, 82-93%, of the dissolved phosphate, total kjeldahl nitrogen, and total phosphorus. Nitrate was produced in both wetland types; however, there was much more nitrate in the effluent from the VFW cells than from the HFW cells. Particulate phosphorus was the major form phosphorus in the treated effluent from both wetland types.

At the conclusion of the experiment, root growth was observed when all material was removed from the wetland vessels. Root growth was thick below the vetiver all the way to the base of the 51 cm sand and gravel or soil media. Roots had even grown into the bottom drain pipes and had surrounded the bottom layers of large gravel sufficiently to make manual gravel removal much more difficult.

5.0 GELITA APA

GELITA Australia manufactures food grade gelatine from cattle hide, and in doing so generates 1.3 ML/day of effluent high in nitrogen (ammonia). While interested in using biological systems for effluent purification, GELITA believes that only plants with a high nitrogen uptake capacity will be able to reduce the nitrogen load in their wastewater to an acceptable level. Consequently, a plant was needed which thrives in water logged conditions, tolerates high level of pollutants, has a high capacity of absorbing these pollutants, particularly nitrogen and has also high biomass production under these extremely adverse conditions. Vetiver grass has all these qualities and holds considerable promise for use in soil based reed beds where high nutrient loads need to be removed.

GELITA Australia has initiated field research in order to:

- demonstrate the suitability of vetiver grass for use in the SBRB system to treat nitrogen rich industrial effluent,
- use the research findings in order to develop and establish a SBRB system that is capable of purifying GELITA's wastewater to a satisfactory level,
- develop a SBRB system using vetiver grass suitable for Australia and world wide.

6.0 SOIL BASED REED BED DESIGN AND CONSTRUCTION AT GELITA

The SBRB has been designed and constructed to comply with the information and experimental data obtained from various publications as well as to meet the requirements of GELITA Pty Ltd. The horizontal subsurface flow system was chosen due to its capability of effectively treating nitrogen compound through nitrification and denitrification processes. Information from literature also claims that various media contain different chemical and physical properties that can result in a higher quality and/or efficiency of wastewater treatment.

6.1 The soils

In this s study, three types of medium were used:

- gravely soil

- sandy loam and
- black cracking clay

The gravel was proven both theoretically and experimentally to have a higher infiltration rate when compared with the sandy loam and black cracking clay (Fig. 1). The higher infiltration rate will essentially cause the wastewater to flow relatively quickly though the system. The faster the wastewater is flows through the system the more volume the wastewater will be able to treat over time. Thus it is expected that the gravel will have the highest volume of wastewater entering the system.

The sandy loam with its hydraulic conductivity of around 0.07 mL/sec should take a longer time period to treat wastewater then the gravel.

The black cracking clay with its extremely low hydraulic conductivity is expected to only treat a very small amount of wastewater at any given time. Ultimately this characteristic will cause the black cracking clay reed bed to be significantly less efficient at treating a larger volume of wastewater then both the sandy loam and gravel reed beds.

Fig. 1: Hydraulic conductivity of the three media used

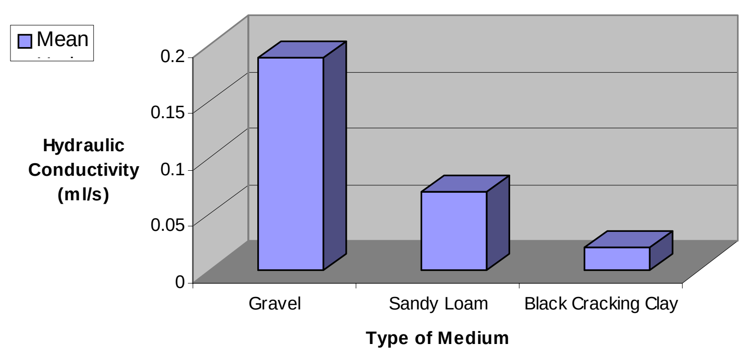


Figure 5.2: Summary of Hydraulic Conductivity Results for gravel, sandy loam and black cracking clay

In addition to the hydraulic conductivity test, chemical analyses of the three media were also carried out as shown in Table 1.

Table 1: Chemical analyses of the three media

Table 1: Chemical analyses of the three media **Profile**	**pH**	**Electrical Conductivity (mS/cm)**	**NO3-N (mg/kg)**	**Organic Carbon** (%)**	**Ca (meq/100g)**
Gravel	**8.3**	**0.219**	**20.7**	**0.20**	**18.2**
Sandy Loam	**6.9**	**0.055**	**18.2**	**0.33**	**9.2**
Black Cracking Clay	**5.3**	**0.422**	**90.2**	**2.60**	**21.0**

The porosity tests will give an indication of the physical constituents of the soil. Table 2 shows the gravel containing the highest amount of particle sizes over 2mm.

Table 2: Porosity of the three media

Type	Initial Weight (g)	Weight of Particles >2mm	Weight of Particles <2mm	Gravel (%)
Gravel	**901.53**	**776.73**	**124.8**	**86**
Sandy Loam	**562.09**	**76.32**	**485.58**	**14**
Black Cracking Clay	**537.86**	**321.29**	**216.47**	**60**

6.2 The Reed Beds Design

The design of the SBRB system incorporated the information gained from the literature and case study research and ideas from specialist in their respective fields. Wetzel (1993) states that the design of a constructed wetland should be 'regarded as a natural integrated ecosystem'. The design of the soil based reed beds can be divided up into three main areas including the box section, the inlet system and the outlet system.

6.2.1 The Box Section

Several factors came into play when the sizing of the SBRB was designed. Limited space, cost, resources and time all played an important part to the scale of the beds. Chervek (2005) advises that a SBRB system requires an aspect ratio (length:width) of around 4:1 and that systems that are longer tend to pond water on the surface. Agreeing with Chervek, Tchobanoglous (1993) advises that typically they vary from 4:1 to 10:1 and states the major problem is surface flow on the reed bed. At Gelita the ratio of 10:1 was built due to the high costs of the High Density Polyethylene liner to suit the aspect ratio. In accordance with Envirowise (2006) a gradient of one (1) percent was used for the SBRBs. It is expected in the long term this will provide enough gradient to adequately allow the wastewater to flow through the bed but also allow a good retention time for treatment. Photo 1 shows the measurements and construction of the SBRBs.

6.2.2 Inlet System

The inlet system was designed so that it could be easily monitored, regulated and altered if necessary. The system was located above the reed bed as this allows for the inlet system to be easily altered in case of failure or serviced if maintenance is required. The inlet must also be designed to allow the water to flow evenly across the reed bed at various depths (Cooper *et al,* 1996. Chervek, 2005). The inlet must therefore allow the water to reach the bottom of the bed near the inlet then flow through the bed. Gravel was placed at the inlet to all the reed beds. Due to its ability to allow a high influx of wastewater (Chervek, 2005) this will help the wastewater to flow to the base of the bed before flowing horizontally through the reed bed (Photo2, left).

Photo 1: Box cut with 1% gradient (left), and lined with High Density Polyethylene sheet and filled with soil (right)

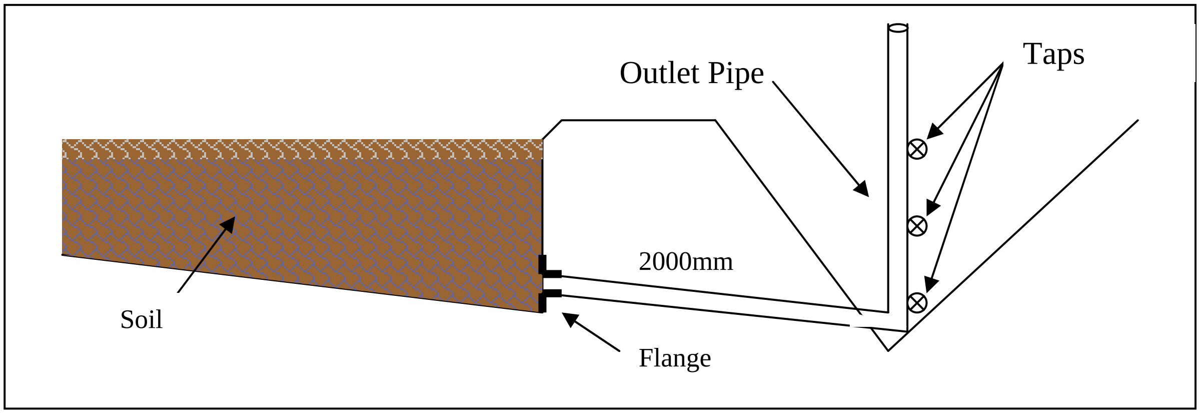
Photo 2: Inlet system (left), and outlet system (right)

6.2.3 Outlet System

The outlet system is not only used for treated wastewater removal but can have a secondary purpose in that it can alter the depth of the water within the bed. This can aid in the treatment of wastewater by influencing plant root and rhizome depth (Cooper *et al.* 1996). The ability to alter the water depth enables the treatment process to be either a constant flow or a batch treatment system. It was decided that the reed beds should have three different heights. The first outlet point will be just below the surface of the bed to allow maximum water in the reed beds. The second one will be around the middle of the bed, which can be used to encourage root growth and the third at the very bottom of the bed to allow for drainage of the system (Photo2, right).

In the design gravel is placed at the outlet end of the bed to prevent sediments from entering the outlet pipe and also to allow the treated water to flow into the drain quickly and easily. Three taps will be installed at the various outlet points to control water depth. A hose will then be used to control where the treated water will flow. Figure 2, outlines the basic design for the outlet pipe.

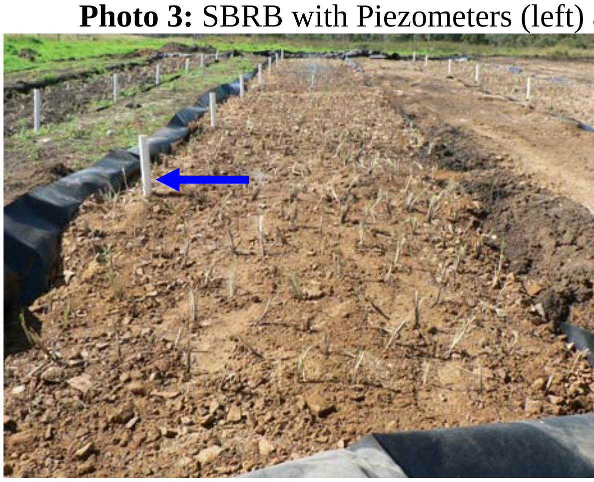
Figure 2: Basic design of the outlet system



6.2.4 Piezometers

To provide extra data for the analysis of the reed bed system, several piezometers were installed along the length of the reed bed to closely monitor the water height and quality through the bed length. The piezometers would act like filters, allowing only water to flow into them for sampling. The design allows each bed to have seven piezometers at even spacing (Photo3).

Photo 3: SBRB with Piezometers (left) and the complete experimental site (right)



7.0 EXPECTED OUTCOMES

It is expected that the Vetiver grass planted in the system will dramatically improve the wastewater treatment process through its many unique characteristics. The extensive root system should enable the plants to penetrate deep down to the base of the reed bed potentially allowing oxygenation to occur from the roots through the entire depth of the reed beds. As the plant is extremely hardy being able to survive very acidic and saline conditions the wastewater treatment processes should not inhibit plant growth or uptake too much.

The efficiency of the SBRBs is determined mainly by the following three factors:

- The quality of the wastewater, which is determined by a number of complex and interdependent variables
- Hydraulic retention time (HRT) is a very important factor as it allows for chemical, biological and physical process to occur within the system.
- The media's infiltration abilities.

It is expected that the HRT for all three beds will vary with the media, climatic and seasonal variations. However, under the same conditions, the gravel bed is more likely to require the lowest HRT to treat the effluent to a certain quality because of it porosity, a good mixture of sand, rock and clay, which is more likely contain a good microbial population to enhance the treatment.

8.0 TREATMENTS

Over the next two years, a combination of treatments will include:

- Various effluent quality out put from the factory
- Various effluent quantity input and flow rate
- Hydraulic retention time
- Others factors determined by result outcomes

9.0 MONITORING

- Effluent quality and quantity output
- Effluent quality in piezometers along the bed
- Effluent quality and quantity at 3 outlet levels
- Others factors determined by result outcomes

10.0 REFERENCES

Brix, H. (1993). Constructed Wetlands for Water Quality Improvement Boca Raton, Lewis Publishers.

Chervek, D. (2005). "The Use of Wetlands as Water Treatment Systems " Retrieved 28 February 2006.

CIWEM (2003). Reed Bed Wastewater Treatment, The Chartered Institution of Water and Environmental Management

Cooper, P. (1993). Constructed Wetlands for Water Quality Improvement Lewis Publishers.

Cooper, P. J., G. Green,M. & Shutes,R (1996). Reed Beds and Constructed Wetlands for Wastewater Treatment. Swindon, WRc plc.

Envirowise (2006). Reed Bed Application, Crown.

Findlater, B. C. and P. F. Cooper (1990). Constructed Wetlands in Water Pollution Control. International Conference on the Use of Constructed Wetlands in Water Pollution Control, Cambridge, UK, Pergamon Press.

Hatano, K., C. Trehin, et al. (1993). Constructed Wetlands for Water Quality Improvement Boca Raton, Lewis Publishers.

Kong, X., W. Lin, et al. (2006). Study on Vetiver's Purification for Wastewater from Pig Farm, Guangdong Academy of Agricultural Sciences.

JTED (2006) Vertical Flow Reed Bed Technology. Volume, 2 DOI:

Liehr, S. K. (2000). Constructed wetlands treatment of high nitrogen landfill leachate Water Environment Research Foundation.

Summerfelt ST, Adler PR, Gleen DM, *et al*. 1999. Aquaculture sludge removal and stabilization within created wetlands. Aquacultural Engineering, 19: 81-92.

Tchobanologlous, g. (1993). Constructed Wetland for Water Quality Improvement. Boca Raton, Lewis Publishers.

Truong, P.N. and Baker, D. (1998). Vetiver grass system for environmental protection. Technical Bulletin N0. 1998/1. Pacific Rim Vetiver Network. Office of the Royal Development Projects Board, Bangkok, Thailand.

Truong, P.N. and C. Smeal (2003). Research, Development and Implementation of the Vetiver System for Wastewater Treatment. S. S. Narong Chomchalow, Pacific Rim Vetiver Network. 2003.

Wallace, S. D. (2002). Use of Constructed Wetlands for Nitrogen Removal. 2002 Annual Conference and Exposition Proceedings, NOWRA.

Wetzel, R. G. (1993). Constructed Wetland for Water Quality Improvement. Boca Raton, Lewis Publishers.

A Brief Introduction to the First Author

Mr Cameron Smeal is the Environmental Manager for the Beaudesert operations of GELITA APA, Australia. He has spent the last 10 years in practical development of industrial waste disposal techniques for Weston Bioproducts and GELITA.

In the last five years he has concentrated on the application of the Vetiver System for the sustainable effluent disposal by land irrigation and currently on the use of vetiver grass in Soil Based Reed Beds and a number of projects determining the long term effects of VS on the soils and other environmental issues.