WORKSHOP 2

VETIVER SYSTEM TECHNOLOGY FOR PREVENTION AND TREATMENT OF POLLUTED WATER AND CONTAMINATED LAND

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1. INTRODUCTION

In the course of researching the application of its extraordinary attributes to soil and water conservation, Vetiver was also found to possess unique physiological and morphological characteristics particularly well suited to environmental protection, particularly in the prevention and treatment of contaminated water and land. These remarkable characteristics include a high level of tolerance to elevated and even toxic levels of salinity, acidity, alkalinity, sodicity, and a whole range of heavy metals and agrochemicals, as well as exceptional ability to absorb and tolerate elevated levels of nutrients to consume large quantities of water in the process of producing a massive growth under wet conditions.

Applying the Vetiver System Technology (VST) as a phytoremediation tool for environmental protection is an innovative approach that has tremendous potential. VST is a natural, green, simple, practicable and cost-effective solution. Most importantly, Vetiver's leaf by-product offers a range of uses from handicrafts, animal feeds, thatches, mulch and fuel, to name just a few.

Its effectiveness, simplicity and low cost makes the VST a welcome partner in the many tropical and subtropical countries that provide domestic, municipal and industrial wastewater treatment, contaminated land and mining wastes phytoremediation and rehabilitation (Truong et al.,2008).

This presentation will concentrate on:

- VST for prevention and treatment of polluted water
- VST for phytoremediation of contaminated land

2. PREVENTION AND TREATMENT OF POLLUTED WATER

VST prevents and treats contaminated water and land in the following ways.

Preventing and treating contaminated water

- Eliminating or reducing the volume of wastewater
- Improving the quality of wastewater and polluted water.

Preventing and treating contaminated land

- Controlling offsite pollution
- Phyto-remediating contaminated land
- Trapping eroded materials and trash in runoff water
- Absorbing heavy metals and other pollutants
- Treating nutrients and other pollutants in wastewater and leachate.

3. SPECIAL FEATURES OF VETIVER GRASS SUITABLE FOR WASTEWATER DISPOSAL AND TREATMENT

- Thick growth, forming a living porous barrier which acts as a very effective filter, trapping both fine and coarse sediment
- Deep, extensive and penetrating root system which can reduce/prevent deep drainage.
- Highly resistance to pests, diseases and fire
- Tolerance to extreme climatic variation such extreme temperature from -15^{o} C to 55^{o} C (Truong et al., 2008). (Kurrup et al., 2008).
    - Tolerance to high altitude (3 500m) and covered by 50cm of snow for one month (Arochas et al (2010))
- Tolerance to prolonged drought, submergence and flood

- High level of tolerance to herbicides and pesticides (Cull et al., 2000).
- Highly efficient in absorbing dissolved N, P, Hg, Cd and Pb in polluted water.
- Vetiver uses more water than other common wetland plants such as *Typha* spp, *Phragmites australis* and *Schoenoplectus validus* (Cull et al., 2000).
- Ability to regrow very quickly after being affected by the above adverse conditions after growing conditions improved or soil ameliorants added
- Very high removal rate of nutrients in water (Vieritz et al., 2003), (Hart et al.. 2003), (Truong, 2003), (Zheng et al, 1997).
- Very high transpiration rate (Truong and Smeal (2003) (Cull et al., 2000).
- High biomass production (Vieritz et al., 2003). (Truong, 2003).
- Vetiver is sterile and non-invasive (Truong and Creighton, 1994) (http://www.vetiver.org/USA_PIER.htm.
- Vetiver has no above or underground stems, it flowers but produce no seeds and is sterile, so no weed potential.

This presentation will concentrate on:

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4. MECHANISM OF DISPOSAL AND TREATMENT OF WASTEWATER.

The Vetiver System can dispose and/or treat wastewater in two ways by:

- Reducing the volume or eliminating the contaminated wastewater by:
    - Land irrigation
    - Wetland
- Improving the quality of polluted water by
    - Trapping debris, sediment and particles
    - Absorbing pollutants and heavy metals,
    - Detoxification of industrial and agrochemicals in wetlands

4.1 Reducing the volume or eliminating the contaminated wastewater

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

Land irrigation: Under glasshouse conditions, a good correlation was established between water use and biomass. From this correlation it was estimated that for ***1kg of dry shoot biomass, vetiver would use 6.86L/day***. If the biomass of 12-week-old vetiver, at the peak of its growth cycle, was 40.7t/ha, a hectare of vetiver would potentially use 279KL/ha/day.

Wetlands: Natural and constructed wetlands have been shown effective in reducing the amount of contaminants in runoff from both agricultural and industrial lands. The use of wetlands for the removal of pollutants involves a complex variety of biological processes, such as microbiological transformations and physio-chemical processes, e.g. adsorption, precipitation or sedimentation. Vetiver wetlands have been successfully used in Australia for sewage disposal, in China for reducing both the volume and high nutrient loads of the piggery effluent, in Thailand and Vietnam for industrial wastewater and for sewage effluent.

4.2 Improving the quality of polluted water

Off-site pollution is the greatest threat to the world environment, this problem is widespread in industrialized nations but it is particularly serious in developing countries, which often do not have enough resources to deal with the problem. Vegetative method is generally the most efficient and commonly used for water quality improvement. However to fulfill this task effectively, the plant species needs to be:

- Tolerant to extremely adverse growing conditions
- Tolerant to high levels of agrochemicals, heavy metals, toxic organic and inorganic compounds (Table 1)
- Tolerant to elevated nutrient levels
- Capable of producing fast growth and high biomass.

Vetiver is one of a very few plants, if not a unique plant, that has the potential to meet all the criteria.

Table 1. Threshold levels of heavy metals to vetiver growth based on single element experiment) (Danh et al., 2012).

Heavy metals	Threshold to growth of most vascular plants (mg kg^{-1})		Threshold to vetiver growth (mg kg^{-1})	Vetiver survival under the highest levels of metals reported in the literature (mg kg^{-1} soil)
	Hydroponic level	*Soil level*	*Soil level*	
Arsenic	0.02-7.5	2.0	100-250	959
Boron				180
Cadmium	0.2-9.0	1.5	20-60	60
Copper	0.5-8.0	NA	50-100	2600
Chromium	0.5-10.8	NA	200-600	2290
Lead	NA	NA	>1500	10750
Mercury	NA	NA	>6	17
Nickel	0.5-2.0	7-10	100	100
Selenium	NA	2-14	>74	> 74
Zinc	NA	NA	>750	6400

Trapping debris, sediment and particles in agricultural lands

In Australia research studies in sugarcane and cotton farms have shown that vetiver hedges were highly effective in trapping particulate-bound nutrients such as P, Ca and herbicides such as diuron, trifluralin, prometryn and fluometuron and , pesticides such as α, β and sulfate endosulfan and chlorpyrifos, parathion and profenofos. These nutrients and agrochemicals could be retained on site if vetiver hedges were established across drainage lines, (Fig 1).

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

Absorbing and tolerating pollutants and heavy metals: The key feature of VS in treating polluted water lies in its capacity to quickly absorb nutrients and heavy metals, and its tolerance to very elevated levels of these elements. Although the concentrations of these elements in vetiver plants is often not as high as those of hyperaccumulators, however due to its very fast and high yield (dry matter production up to 100t/ha/year), vetiver can remove a much higher quantity of nutrients and heavy metals from contaminated lands than most hyper-accumulators. (Table 2)

Table 2. The highest concentrations of heavy metals accumulated in the roots and shoots of vetiver reported in the literature (Danh et al., 2012).

Heavy metals	Soil condition		Hydroponic condition	
	Roots (mg kg^{-1})	Shoots (mg kg^{-1})	Roots (mg kg^{-1})	Shoots (mg kg^{-1})
Lead	4940	359	≥ 10,000	≥ 3350
Zinc	2666	642	>10,000	>10,000
Chromium	1750	18		
	953	65	900	700
Copper	268	11.2		
Arsenic	28	17		
Boron	~ 25	~ 44	2232	93
Cadmium				

In Australia, in a project to demonstrate the effect of the VS in reducing the volume and improving the quality of effluent showed that after five-months of growth, the total N levels in the seepage collected after 2 rows was reduced by 83% and after 5 rows by 99%. Similarly the total P levels were reduced by 82% and 85% respectively (Fig.2).

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

In Vietnam, wastewater from pig farm contains very high N and P and also heavy metals has been successfully treated with vetiver floating pontoons, (Photo 2).
Photo 2: Vetiver floating pontoons on a pig farm in Vietnam

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

5. CASE STUDIES.

5.1 Sewage effluent treatment:

5.1.1 Disposal of domestic sewage effluent

The first application of the VS for effluent disposal was conducted in Australia in 1996 for the treatment of the effluent discharge from a toilet block in a park. With the cultivation of about 100 vetiver plants in an area less than 50 m^2, the wastewater have been completely dried up (Figure 9). Whilst other plants such as fast growing tropical grasses and trees, and crops such as sugar cane and banana have failed

Groundwater monitoring of the vetiver cultivation (collected at 2 m depth) showed that after passing through 5 rows of vetiver, the levels of total N reduced by 99% (from 93 to 0.7 mg/L), total P by 85% (from 1.3 to 0.2 mg/L), and fecal coliforms by 95% (from 500 to 23 organisms/100 mL). These levels are well below the thresholds used by Australian Environmental Authority of total N < 10 mg/L; total P < 1 mg/L and *E. coli* < 100 organisms/100mL. (Figure 10).

***Vetiver planting to absorb effluent discharge from a toilet block in a park in Australia*.**

5.1.2 Disposal of community sewage effluent

Watts Bridge airfield is a small recreational airfield in Queensland. Vetiver was planted on an area of 100 m^2 to dispose a small volume sewage effluent (Figure 11), with the results presented in Table 3.

Table 3. Water quality before and after treatment with vetiver at Watt Bridge.

Variables	Inflow	Outflow	Reduction (%)
Average daily flow (L)	1670	Almost nil	Nearly 100
Average total N (mg/L)	68	0.13	Nearly 100
Average total P (mg/L)	10.6	0.152	Nearly 100
Average faecal coliform	>8000	10	Nearly 100

***Sewage effluent disposal for small community in Australia*.**

5.1.3. Disposal of Municipal Sewage Effluent

The sewage treatment plant for Toogoolawah, a small town in subtropical Australia, was built in the 1970s. The plant was constructed as a primary sedimentation (Imhoff Tank) followed by three sewage storage ponds. The effluent from the ponds was designed to flow down into a swamp before it overflowed into the local creek. The plant construction was based on a very simple design but it was effective. With the recent changes to license conditions imposed by the Environmental Protection Agency (EPA), the plant no longer complies with the license and so an upgrade of the plant was required. Various options were considered such as a nutrient removal plant, a sand filter or a rock filter. These options are expensive and would require expensive ongoing operational costs. The council then considered a VPT treatment system that would take up most of the water, as well as remove nutrients, organic compounds and heavy metals from the sewage effluent (Ash and Truong, 2003).

The vetiver treatment has composed of two components (Figure 12):

- Hydroponic treatment of effluents in the storage ponds
- Ephemeral wetland

The results of the treatment over the period 2002 - 2004 are summarized in Table 4.

Table 4. Effluent quality characters before and after the vetiver treatment.

Tests **(license requirements)**	***Effluent Input***	***Effluent Output***
PH (6.5 to 8.5)	7.3 to 8.0	7.6 to 9.2
Dissolved Oxygen (2.0 minimum)	0 to 2 mg/l	8.1 to 9.2 mg/l
5 Day BOD (20 - 40 mg/l max)	130 to 300 mg/l	7 to 11 mg/l
Suspended Solids (30 - 60 mg/l max)	200 to 500 mg/l	11 to 16 mg/l
Total Nitrogen (6.0 mg/l max)	30 to 80 mg/l	4.1 to 5.7 mg/l
Total Phosphorous (3.0 mg/l max)	10 to 20 mg/l	1.4 to 3.3 mg/l

- **Large scale application**

The Boonah town, near Brisbane, needed to upgrade its sewage treatment plant to comply with new environmental protection law. Subsequently, the preliminary design investigations have been undertaken to develop the dedicated irrigation solution, and in particular a variation to use Monto Vetiver grass ephemeral wetland for the disposal area.

Results to date have exceeded expectations. Only 15 months after planting, 4 ha of vetiver has totally absorbed between 500 and 600 KL of effluent a day. Ground water monitoring showed that practically no leaching occurred during dry periods and very little during wet periods and nutrient levels in these samples were well below the license limits. Ground water monitoring is continuing.

***Municipal sewage effluent disposal for small town in Australia*.**

5.2 Disposal of municipal landfill leachate

Disposal of landfill leachate is a major concern to all large cities, as the leachate is often highly contaminated with heavy metals, organic and inorganic pollutants. Results in Australia, Mexico and USA showed that vetiver growth is not affected by this highly polluted water and grows vigorously.

In Australia, Stotts Creek Landfill is a major waste depot of the Tweed Shire, New South Wales, Australia. Disposal of leachate is a major concern of the Shire as the landfill site is close to agricultural areas. An effective and low cost leachate disposal system was needed, particularly during summer high rainfall season. Following capping with top soil, vetiver was planted on the surface of landfill mound and irrigated with leachate from collecting ponds (Figure 14). Results to date have been excellent. In the second year, vetiver with 3 m high forming the thick and tall walls was recorded. The growth was so vigorous that during the dry period, there was not enough leachate in the ponds to irrigate both the old and new plantings. A planting of 3.5 ha in January 2003 has effectively disposed of 4 ML a month in summer and 2 ML a month in winter (Percy and Truong, 2003).

Municipal landfill leachate disposal for small town in Australia.

In Mexico, PASA, which is the largest solid waste management company in Mexico, currently applies VS for landfill leachate disposal, leachate seepage mitigation and for erosion control on landfill side slopes. The company has three projects underway, one each at Leon, Poza Rica, and Villahermosa. These projects have some 300,000 vetiver plants in the ground (Figure 18). .

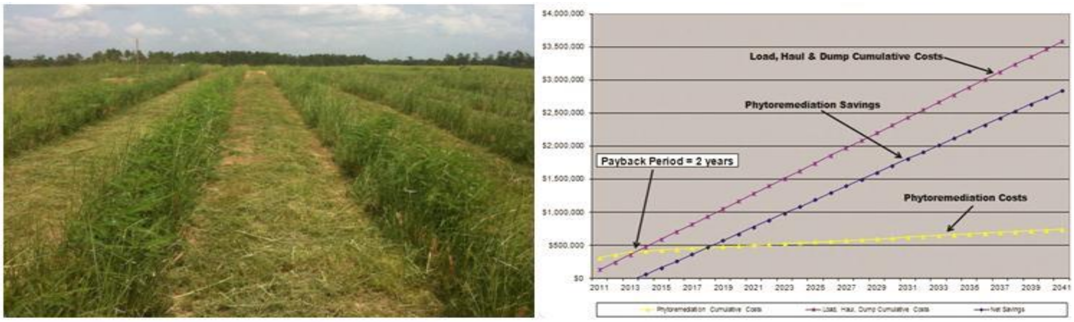
Early stage of vetiver establishment at Leon (left) and Poza Rica (right).

In the USA, the phytoremediation system using VS was set up to utilize up to 14 ML/year (3 million gallons) of leachate. This was the first of its kind for large scale project in the US and Western Hemisphere to use vetiver grass (Truong et al., 2012).

With an area of 3 acre cultivated with over 50,000 vetiver plants (Figure 23), the system has performed as designed and 100% of leachate generated has been utilized on site, well ahead of anticipated results. This approach greatly reduces costs in an environmentally friendly manner**.** The results to date have exceeded expectation in term of utilization and cost saving:

- Approximately 500,000 gal processed in first 4 months, greater than 1 million in the first year
- $150,000 transportation and disposal costs avoided in the first year
- Pre-vetiver leachate disposal cost = $0.09/gal
- Post-vetiver leachate disposal cost = <$0.01/gal
- Return on initial capital investment: only 2– 3 years
- $3 million expected savings over 30 years

Due to the outstanding performance, this project was awarded a "2012 Grand Prize – Small project for Excellence in Environmental Engineering" by American Academy of Environmental Engineers (http://www.aaee.net/E32012GPSmallProjects.php).



Disposal of industrial landfill leachate in Mississippi USA

5.3 Industrial wastewater treatment:

The disposal of industrial wastewater in Australia is subjected to the strict environmental guidelines enforced by the Environmental Protection Authority, EPA. The most common method of treating industrial wastewater in Australia is by land irrigation, which is presently based on tropical and subtropical pasture plants. However, with limited land area available for irrigation, these plants are not efficient enough to sustainably dispose of all the effluent produced by the industries. The existing system used pasture species which could not meet the new EPA standards. Therefore, to comply with the new standards, most industries are now under strong pressure to upgrade their treatment processes by adopting VS as a sustainable means of disposing wastewater. VS has been adopted and successfully used to treat/dispose of effluent generated by the following two factories:

5..1 Food processing factory

GELITA APA, a gelatin factory in Queensland, Australia, which extracts gelatin from cattle hide using chemical processes involving strong acids, lime and hydroxides. The effluent from the processing plant, 1.3 ML/day, is highly saline (average 600 mS/cm), alkaline and has a high organic matter content. The MEDLI computer model (see 4.4.1) output based on an assumed maximum annual effluent output of 584 ML, N concentration of 300 mg/L and 121 ha available for irrigation shows that vetiver requires the least land for sustainable irrigation in both N and effluent volume amongst the three grasses (Table 5). A reduction from 130 to 80 ha for the treatment of the effluent would result in significant cost savings of the factory (Truong and Smeal, 2003; Smeal et al, 2003).

Table 5. Land area required by three grasses for irrigation and N disposal

Plants	**Land needed for irrigation (ha)**	**Land needed for N disposal (ha)**
Vetiver	80	70
Kikuyu	114	83
Rhodes	130	130

5..2 Cattle abattoir (slaughter house)

TEYS Bros, a beef abattoir in Queensland, processes about 210 000 cattle per year for both domestic consumption and export. Effluent generated by the abattoir, approximately 1.7 ML/a day, with total N of 170mg/L and 32mg/L of total P. MEDLI simulations predict that:

- When vetiver grass was used, approximately 1.24 ML/day of effluent can be sustainably irrigated on the 42.3ha of available land.
- With Kikuyu grass pasture only approximately 0.8ML/day effluent can be sustainably irrigated on the same area.

- The above result indicates that, vetiver planting would provide an improvement of 55% over Kikuyu in planting area (Truong and Smeal, 2003).

5.3 Fish processing factory

In the Mekong Delta of Vietnam, a demonstration trial was set up at a seafood processing factory to determine the treatment time required to retain effluent in the vetiver field [Hydraulic Retention Time (HRT)] to reduce nitrate and phosphate concentrations in effluent to acceptable levels. The experiment started when plants were 7 months old. Water samples were taken for analysis at 24 hour interval for 3 days. Analytical results showed that total N content in wastewater was reduced by 88% and 91% after 48 and 72 hours of treatment, respectively. The total P was reduced by to 80% and 82% after 48 and 72 hours of treatment, respectively. The amount of total N and P removed in 48 and 72 hour treatments were not significantly different

A seafood processing factory the Mekong Delta

5.4 Computer model for small volume wastewater treatment

A computer model was specifically designed for use in small scale projects to treat low volume domestic and small community wastewater in developing as well as developed countries. To date, all the small scale wastewater treatment projects using VS is based on trial and error method and experience. To overcome this, a scientifically based Model is needed to convince authorities of its effectiveness and accuracy. Obviously for small scale application, which produces low volume effluent, the long term and accurate parameters are not easily available or nonexistent, hence an accurate determination of the land area needed is very difficult to make.

To fulfill this need EDVI-2 Model (Effluent Disposal by Vetiver Irrigation) was developed specifically to treat small volume input from:

- Individual household and small communities sewage effluent and small volume landfill leachate
- Industrial wastewater from small factories or cottage industries such as coffee farmer or small coffee cooperations in Latin America and globally

6 PHYTOREMEDIATION OF CONTAMINATED LAND

6.1 Special features of vetiver grass suitable for phytoremediation of contaminated land

In addition to the attributed listed in section 3, these additional features make vetiver highly suitable for phytoremediation of contaminated land:

- Highly tolerant to soil high in acidity, alkalinity, salinity, sodicity and magnesium (Danh et al., 2012).
- Highly tolerant to Al, Mn, As, Cd, Cr, Ni, Pb, Hg, Se and Zn in the soil (Danh et al., 2009; Truong and Baker, 1998).
- Ability to regrow very quickly after being affected by the above adverse conditions after growing conditions improved or soil ameliorants added
- Tolerance to extremely high level of nutrients in soil (Wagner et al., 2003).
- Very high removal rate of nutrients in soil (Vieritz et al., 2003), (Hart et al.. 2003), (Truong, 2003), (Zheng et al, 1997).

6.2 Case Studies of phytoremediation of contaminated land

- ***Ammonia and nitrate contaminated site at Bajool***

This site was contaminated with extremely high levels of Ammonia and Nitrate as a result of explosive manufacturing. This site has the following features:

- Land surface area: 7 300m2
- Soil depth; 2.5m to 3.0m
- Contaminate soil volume: 20 000m3
- **Soil Ammonia level**, ranging from 20 -1 220mg/kg, **averaging 620mg/kg**
- **Soil total N level**, ranging from 31-5 380mg/kg, **averaging 2 700mg/kg**
- **Water Ammonia level**, ranging from **235-1 150mg/L**, with one sample at 12 500mg/L

- **Water total N level**, ranging from **118 – 7 590mg/L**, with one sample at 18 300mg/L

The objectives were to plant vetiver grass as a phytoremediation measure to remove Ammonia and Nitrate from this site and to stabilise the site, preventing offsite pollution by runoff with potential to contaminate the local environment

Based on the above average levels of NH3 and total N, the grand total N content of the top soil (20cm depth) is 0.66kgN/m^2, which is equivalent to 6 600kgN /ha. Vetiver research has shown that Vetiver under optimum moisture supply can be grown on soil applied up to 8 000kgN/ha (Wagner *et al* 2003). Hence it is projected that most of the N in the fill will be removed by vetiver in less than 4 years under favourable weather and at most 6 years under normal weather conditions. One year after planting, the results were outstanding despite severe drought, excellent growth resumed following heavy rain six months later. With this high growth rate, this planting removed at least 629kg/ha/year, and possibly much higher, at 1100kg/ha depending on the rain, indicating that this projection is on course.


Extremely contaminated with high levels of Ammonia and Nitrate as a result of explosive manufacturing.

- ***Ammonia, nitrate and agro-chemical contaminated site at Peak Downs***

As at Bajool site, the Peak Downs site was contaminated with Ammonia, Nitrate and agro-chemicals used for weed control around the mine. The contamination level at the Peak Downs varies greatly from very low to very high depending on the location of the site

- Soil Ammonia level, ranging from 20-3 800mg/kg
- Soil total Nitrate level ranges from <10 to as high as 7 620mg/kg.

Excellent growth was recorded as expected under good irrigation and high N level in the soil. To satisfy the P demand of vetiver under this high N supply, superphosphate fertilizer was applied at planting.

The above results indicate that vetiver grass can be established on soils contaminated with elevated levels of Ammonia and Nitrate. With appropriate management and maintenance, vetiver can be effectively used for decontamination of these sites.

6.3 Rehabilitation and phytoremediation of Mining wastes

(Please refer to Workshop 3: Reclamation of Mine Tailings)

7. CONCLUSION

Application of VST for the prevention and treatment of polluted water and contaminated land is a new and innovative phytoremedial technology. The approach is grounded in science and backed by data from full-scale, successful applications across the world. It is a green and environmentally friendly wastewater treatment technology as well as a natural recycling method.

As a new technology, it has to be learned and applied correctly to achieve its effectiveness, simplicity and low cost.

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