Sustainable Alternative for Waste Water Treatment Using REED BED SYSTEM

By Ajay Singh and Vaishali

Phytoremediation: Using Green Plants to Clean Up Soil, Groundwater and Wastewater

Phytoremediation combines the Greek word 'phyton' (plant), with the Latin word 'remediare' (to remedy) to describe a system whereby certain plants, growing in a contaminated matrix working together with soil organisms, can transform soils, sludge, sediments and water contaminated with organic and inorganic contaminants into harmless and, sometimes, valuable forms. It can also be defined as:

"An in situ remediation technology that utilizes the inherent abilities of living plants to remove, detoxify or immobilize environmental contaminants in a growth matrix (soil, water or sediments) through the natural biological, chemical or physical activities and processes of the plants".

In this article we are more concerned about Macrophytes i.e. sedges, reeds, as they play an important role in treatment of water within a reed bed.

Plants are unique organisms equipped with remarkable metabolic and absorption capabilities, as well as transport systems that can take up nutrients or contaminants selectively from the growth matrix, soil or water. Phytoremediation takes advantage of the unique and selective uptake capabilities of plant root systems, together with the translocation, bioaccumulation, and contaminant storage/degradation abilities of the entire plant body.

Phytoremediation involves growing plants in a contaminated matrix, for a required growth period, to remove contaminants from the matrix, or facilitate immobilization or degradation (detoxification) of the pollutants.

There are several ways in which plants are used to clean up, or remediate, contaminated sites. To remove pollutants from soil, sediment and/or water, these plants and their microbial-active rhizosphere (root zone of influence) can break down, or degrade organic pollutants or contain and stabilize metal contaminants by acting as filters or traps. The uptake of contaminants in plants occurs primarily through the root system, in which the principal mechanisms for preventing contaminant toxicity are found, with the remaining water removed via evaporation and transpiration. The range of

Figure 1

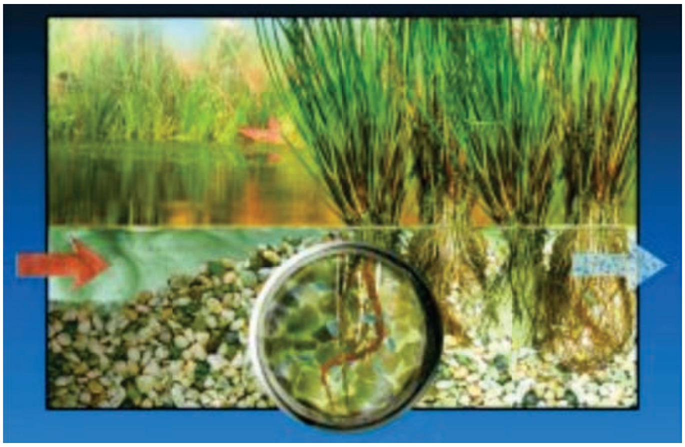

Figure 2

biological treatments for environmental problems, as described by the term phytoremediation, actually consists of several specific processes:

Type	Process Involved	Pollutants Treated
Phyto-extraction	The plants are used to concentrate metals in parts harvestable (leaves and roots)	Cadmium, cobalt, chromium, nickel, mercury, lead, selenium, zinc.
Rhizo-filtration	Plants roots are used to absorb, precipitate and concentrate heavy metals from contaminated liquid effluents and to degrade organic compounds.	Cadmium, cobalt, chromium, nickel, mercury, lead, selenium, zinc radioactive isotopes, phenolic compounds.
Phyto-stabilization	Metal-tolerant plants are used to reduce the mobility of metals and prevent their passage to ground water or the air.	Lagoons rid of mineral deposits. Proposed for phenolic and chlorinated compounds.
Phyto-stimulation	Root exudates promote the development microorganisms (bacteria and fungi) capable of biodegrading compounds.	Petroleum hydrocarbons and polyaromatic, benzene, toluene, atrazine, etc.
Phytovolatilization	Plants take up heavy metals and organic compounds, bind or modify them and release the by-products into the atmosphere via transpiration.	Mercury, selenium, and chlorinated solvents (tetraclorometano and trichloromethane).
Phyto-decomposition	Both aquatic and terrestrial plants capture organic compounds and store them or decompose them to less toxic or non-toxic byproducts.	Munitions products (TNT, DNT, RDX, nitrobenzene, nitrotoluene, atrazine, chlorinated solvents, DDT, phosphate pesticides, phenols and nitriles, etc)

Table 1

Phytoremediation technologies can be developed for different applications in environmental cleanup.

Rhizofiltration as mentioned in Table 1 is a phytoremediation technology which uses plants roots to readily absorb, concentrate and/or precipitate the water and nutrients essential for growth, as well as other non-essential contaminants including metals. It involves construction of managed wetlands or reed beds for the treatment of variety of waste streams, including municipal and industrial wastewater and metal-contaminated waters such as acid-mine drainage.

This variation of phytoremediation uses plants that remove metals by sorption, which does not involve biological processes. In its reliance on surface adsorption as the primary mechanism for removing metals from waste streams, other slower mechanism underlying Rhizofiltration may also occur: these might include biological processes (intracellular uptake, deposition in vacuoles and translocation to the shoot), or precipitation of the metal from solution by plant exudates.

Plants Used for Phytoremediation Of Wastewater

According to the requirement of accumulation or removal of pollutant, specific plants are used for specific purpose.

Like Brassica juncea plant (Indian mustard greens) is widely used in water treatment for the accumulation of selenium, sulfur, lead, chromium, cadmium, nickel, zinc, and copper while plants of Compositae family are symbiotic with Arthrobacter bacteria and are capable of accumulating cesium and strontium from waste water.

Focus

In this article we are more concerned about Macrophytes i.e. sedges, reeds, as they play an important role in the treatment of water within a reed bed. They directly take-up nutrients and pump oxygen into the substrate and provide a food source for the micro-organisms responsible for breaking down pollutants. The Common Reed (Phragmites Australis.) has the ability

Figure 3

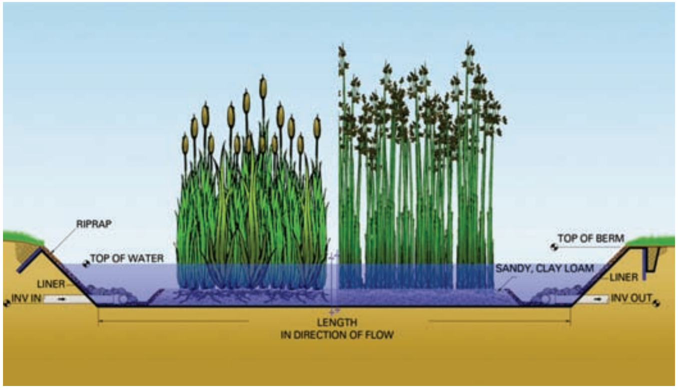

Figure 4

to transfer oxygen from its leaves, down through its stem and out via its root system in the gravel bed. This encourages micro-organisms that digest the pollutants in sewage to colonize the area. As a result of this action, a very high population of micro-organisms occurs in the rhizosphere, with zones of aerobic and anaerobic conditions. Therefore with the wastewater moving very slowly and carefully through the mass of reed roots, this liquid can be successfully treated, in a manner somewhat similar to the conventional biological filter bed systems of sewage treatment plants.

Until recently, Phragmites australis (the Common Reed) and Tyhpa orientalis were the main reeds used in reed beds as they have most extensive root system. However, with the understanding of reed beds growing continuously many new plant species are being used, such as, Lomandra hystrix, Baumea articulata and Schoenaplectus mucronatus.

Along with Reeds we will also look into the mono- and mixed-culture of Reeds and Canna Indica. Its a tropical herb belonging to the family Cannaceae, which can be used for the treatment of waste waters through constructed wetlands. It is effective for the removal of high organic load, color and chlorinated organic compounds. It plays major role in the reduction. They supply oxygen to the soil in the root zones. Using this oxygen, soil bacteria break down organic compounds in grey water and render the water clean.

Both the plants absorb and bio-accumulate toxic trace elements, including heavy metals such as lead, cadmium and selenium. Heavy metals are closely related to the elements plants use for growth.

What is a Reed Bed?

A reed bed is essentially a channel, lined with an impermeable membrane, which is filled with gravel, soil or sand and planted with macrophytes used to treat wastewater. The system is then fed effluent and drained by gravity.

Wastewater, black or grey, is passed through the root zone of the reeds where it undergoes treatment. Inlet and outlet pipes are positioned below the gravel surface, so that the water always remains below the gravel surface, thus excluding human exposure to the wastewater, mosquito breeding and unpleasant odors. The treated water can be used for lawns, gardens and fruit orchards.

They use both physical and biological filtration to clean water. Plants oxygenate the water and reduce nutrients by up to 60%. Pathogens are typically reduced by up to 98% and total suspended solids to levels below international standards.

Chemicals are not required and, provided that just over one meter of hydraulic head is available between the process and final discharge point for the treated effluent.

When sufficiently robust reed species are planted in self-contained, artificially engineered, wetland ecosystems, they are particularly known as Reed Bed System. Canna Indica can also be planted along with Reed plants in it.

How Do Reed Beds Work?

- Reed bed works on the principle of Rhizofiltration as described earlier.
- Primary treated effluent from the house is initially filtered prior to entering the reed bed through an effluent filter fitted to the grey water collection tank or septic tank outlet pipe.
- After filtration of these large solids/floatables the wastewater undergoes many processes as it passes through the reed bed.
- The treated water is then allowed to either flow in a water body or re-used for horticulture.

Reed beds are generally designed to detain the wastewater for a period of 5 to

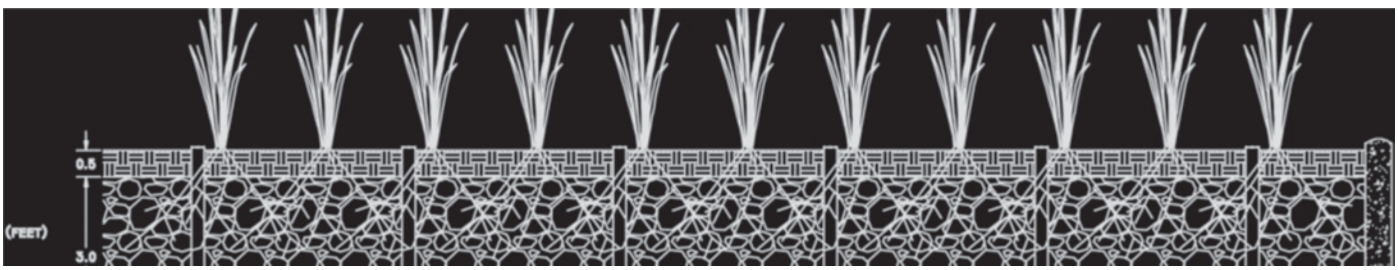

Figure 5: Constructed Wetland Section

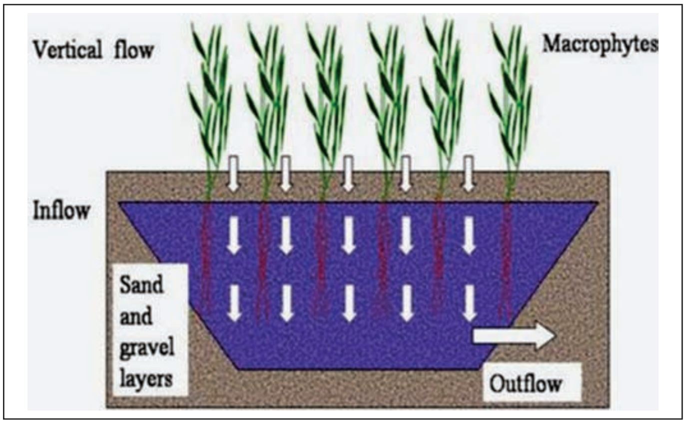

Figure 6

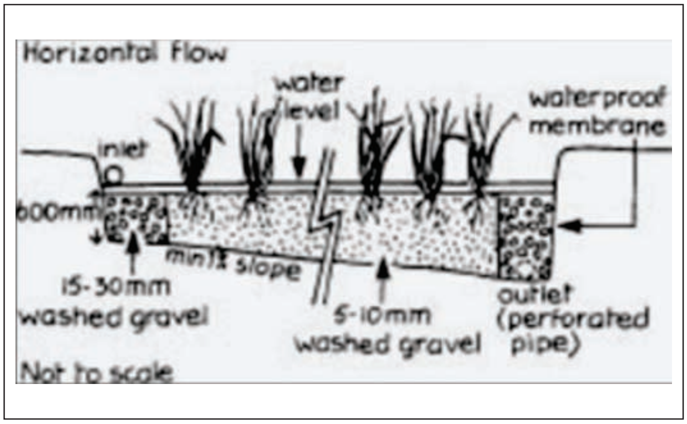

Figure 7

7 days. This residence time aids with the treatment by allowing sufficient time for the settling and filtering of suspended solids, nitrification/denitrification to occur, fixation onto the substrate, breakdown of organic matter and nutrient removal via micro-organisms and plant uptake. Residence time is generally governed by the surface area and depth of the reed bed.

Types of Reed-Beds

There are three different types of systems that have been developed:

- Horizontal flow reed-beds
- Vertical flow reed-beds
- Down-Flow Reed-beds

Horizontal Flow Reed-Beds: Horizontal Flow systems only work when the effluent is of low strength. They are not to be used to treat septic tank effluent, as this is too strong. They are also of no real use for reducing ammonia levels, but they can reduce the level of BOD (Biochemical Oxygen Demand) and SS (Suspended Solids) in sewage treatment plant effluent. Horizontal flow reed-beds should only be considered for tertiary treatment after a full sewage treatment plant. A typical application would be to treat the discharge from a slightly undersized package sewage treatment plant which is failing to meet its discharge permit standard for BOD and Suspended Solids.

Vertical Flow Reed-Beds: Vertical flow systems are more efficient than horizontal flow reed-beds and can handle stronger strength effluent. They can reduce ammonia as well as BOD and SS levels. It is usual for there to be two reed-beds installed, one after the other down the slope of the site. Vertical flow ones can be used to treat septic tank effluent.

Down-Flow Systems: Multi-stage reed-bed systems, incorporates two stages of vertical flow. They work on a 'fill and drain' system, where one bed fills over 12 hours whilst the other one drains and vice versa. The idea is that as the effluent drains out of the gravel, air is pulled in and helps to form an aerobic bacterial colony on the gravel surface to digest the pollutants. These systems require the use of electric pumps, timers and control panels as the effluent is switched from one bed to the other every 12 hours.

Construction of Reed Bed

Estimating the Size of Reed Bed:

1. Length to Width Ratio

The length to width ratio of the reed bed area is between 3:1 and 5:1.

2. Residence Time & Depth

The rule-of-thumb method to be followed for the designing is to give per

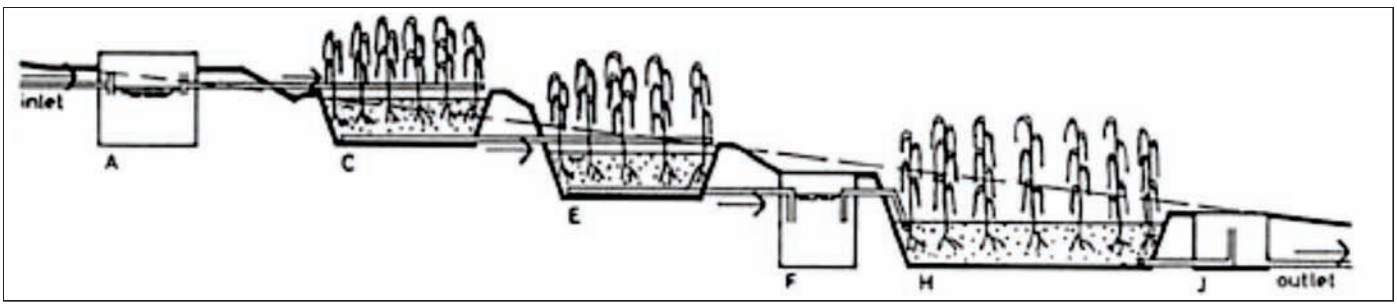

Figure 8

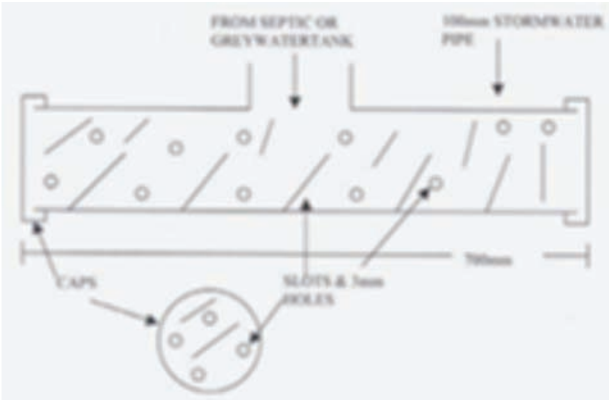

Figure 9

person surface areas which will result in residence time of just about 7 days, which should be ample to ensure sufficient treatment in the common situations. Smaller surface areas are required for "grey water only" reed beds due to the decreased hydraulic and pollutant loads compared to combined black and grey water (septic tank effluent).

While the standard reed bed water depth is taken as 0.5 meters, if, for some reason, the reed bed is going to have a water depth other than the standard 0.5 meters, then different surface areas will be necessary to achieve the desired residence time of 7 days. Surface areas for a range of water depths are provided in Table 2.

Outlet Pipe Height (OP) (m) (from bed surface)	Surface Area / Person (m^2) (Combined black and grey water)*	Treatment Volume (L) (OPD x SAP x # people x Porosity†)	Residence Time (Days)
0.3	6.5	3120	6.78
0.4	5	3200	6.95
0.5	4	3200	6.95
0.75	3	3600	7.83

Table 2 († Based on 20 mm gravel with a porosity of 0.4, * Based on wastewater generation of 460 L (115 lpd & a 4 person household)

3. Estimation of Residence Time

The basic formula which is applied to calculate the residence time for the waste water to be treated through reed bed is:

Residence time = Reed Bed Volume X Porosity/Daily Wastewater Generation

Example: The size of the reed bed was based on a surface area of $3m^2$ per person for a 4 person household. The reed bed was 6m long, by 2m wide and 0.75m deep. The residency time was found to be 8days based on a gravel porosity of 0.4, reed bed storage volume $9m^3$ (6m x 2m x 0.75m) and a wastewater generation of 460L/day.

Residence Time = (6m x 2m x 0.75m) x 0.4/460 = $9m^3$ x 1000 x 0.4/460 ~ 8 days

4. Site Selection

A suitable site should provide good sunlight for reed growth and provide fall for the effluent leaving the primary treatment unit. Those sites on slopes may need a large length to width ratio, as the reed bed will have to follow the contour. Any slope in the design is not to exceed 1% and may be less than 1% but greater than 0%.

5. Planting Out the Reed Bed

Macrophytes should be planted at a density of at least 4 to 5 clumps per square meter (approximately 30-40cm apart), with the rhizomes measuring approximately $15cm^3$, the denser they are planted, the better! All shoots/stems should be trimmed to a length of 20cm before placing the clump in the gravel. Reeds will grow best if it is situated in a sunny location.

6. The Use of Liners for Reed Bed Construction

The lining of a reed bed should be impervious, durable and able to resist penetration by macrophyte roots. If using plastics, it is advisable to lay sand or geo-textile under and over the plastic liner to prevent piercing by gravel, subsurface rock or tree roots.

Alternative lining materials and installation methods must be supported with engineering specifications. Acceptable liners are:

- A double layer of construction grade PVC liner (minimum 0.2mm thickness per layer)

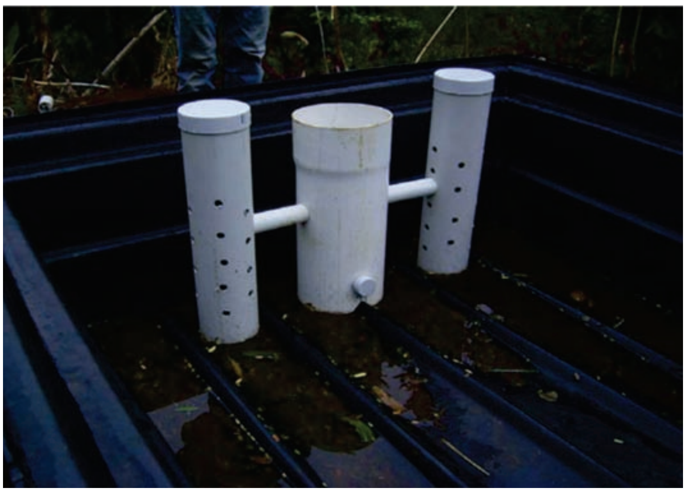

Figure 10

Figure 11

- A suitable thickness of reinforced concrete.

If a liner is used as a membrane, due to financial constraint then one should consider the following points:

- One should consider using a HDPE liner, a minimum of 0.75mm thick.
- Care should be taken to ensure the hole you dig is free from trees roots or any sharp objects.
- The liner should be placed between a protective layer of geo-textile or a similar product, such as, old carpet.
- Care should be taken when placing the gravel into the reed bed so sharp points do not puncture the liner.
- Care should be taken when working around the reed bed with any tools or similar.

7. Choosing Media

The choice of bed media, gravel, soil or sand, is dependent upon the particular application requirements.

- Gravel is less active microbiologically, but allows a faster flow of water. For this reason, gravel has commonly been used in secondary and tertiary sewage treatment applications and in mine waste water treatment where the plants help to keep the water oxygenated thus encouraging the deposition of insoluble metal ions precipitates.
- Soil has commonly been used for primary and secondary treatment of industrial effluents. Certain soil minerals actually encourage the deposition of metal ions, phosphate and sulphate. Soils can therefore be custom-engineered to treat particular effluent streams.
- The ability of clay particles and humic materials to entrap polluting.

8. Inlet and Outlet Structures

There have been many varieties of inlet and outlet structures. Traditionally the inlet and outlet structures consisted of perforated T-pipes. More recent designs have used two 150mm storm water pipe "towers" connected together or have used arched trenching. Essentially whatever design is used for inlet and outlets they must be easily accessed for maintenance.

It is advisable that:

- The outlet pipe should be placed as close to the bottom as possible to allow complete drainage of the reed bed if major maintenance is required.
- The inlet pipe should be placed as close to the gravel surface as possible but remain covered by gravel.
- The gravel coverage is required to prevent vermin entering the inlet pipe and then entering the house and to prevent the escape of unpleasant odors.

Operation & Maintenance of Reed Bed System

Harvesting the Macropthyes

Harvesting is undertaken to remove contaminants from the reed bed and promote macrophyte growth.

- Harvested vegetation can be used as mulch on the reed bed. If mulching

Figure 12

Figure 13

the reed bed, ensure that the mulched material placed on the reed bed doesn't prevent the re-growth of new shoots.

- Studies have shown that mulching the reed bed attract compost worms that helps "transport" solids in the reed bed to the gravel surface that would otherwise clog the reed bed, and thus having a positive effect on the treatment performance of the reed bed.
- Some recommend that harvesting in late spring and then again in early to mid-autumn prior to senescence. Senescence: time during winter months when reeds stop growing and die-back to the roots.
- If possible, the reed bed should be decommissioned during harvesting.
- It is the aim to harvest the above gravel portion before translocation of nutrients below the gravel surface. The reed rhizomes will send out new shoots after senescence, usually when the weather starts to get warmer.

Altering the Height of Wastewater in a Reed Bed

Lowering the height of the water in a reed bed can stimulate root growth and aid in treatment performance by:

- Drying out the upper layer of gravel,
- Oxygenating the exposed area, and
- De-clogging the reed bed

Water height should lower in summer when micro-organism activity is at its greatest and higher in winter when micro-organism growth slows down. A drop in water height of 200mm should be sufficient.

Power Requirement

Unless the site has a decent gradient, it is not usually possible to avoid the need for electrical power when designing a reed bed system. Even simple horizontal flow designs usually need control systems in order to ensure that surge flows don't swamp the system. In the case of Vertical flow and down-flow reed beds, a suitable electrical pumping system is required.

Prominent Beneficiaries of Reed Bed System

1) Phytomediation at Amarnath Pilgrimage (Location: Amarnath, Designed Capacity: 150 KLD, Impact: BOD is less than 15)

2) Ajay Kumar Garg Engineering College (Location: Ghaziabad, Design capacity: 3 KLD)

Impact:

- BOD and COD removal are 81.3 percent and 79.9 per cent respectively
- Faecal coliform levels reduced 85%

3) Centre for Science and Environment (Location: Delhi, Design Capacity: 8 KLD)

Impact:

- Efficiency of the system is 90% in terms of BOD removal
- Requirement for horticulture and gardening is met by the treated wastewater

4) Mughal Sheraton Hotel (Location: Agra, Design Capacity: 400 KLD)

Impact:

- Reused locally for irrigation purposes

5) Aravind Eye Hospital (Location: Pondicherry, Design Capacity: 320 KLD)

Impact:

- BOD reduction 98%
- COD reduction 96%
- TDS reduction 96%

6) Shri Ram School (Location: Delhi, Design Capacity: 4 KLD)

Figure 14

Figure 15

Impact:

- BOD and COD have reduced by 74.1 per cent and 68.7 per cent, respectively
- Nitrate content removal is 90.8 %

Advantages of Reed Bed System

- The prior most benefit of such a system is that it is completely sustainable.
- The other main advantage is financial, because it can be as much as 30% cheaper to incorporate a reed system than a present day underground system.

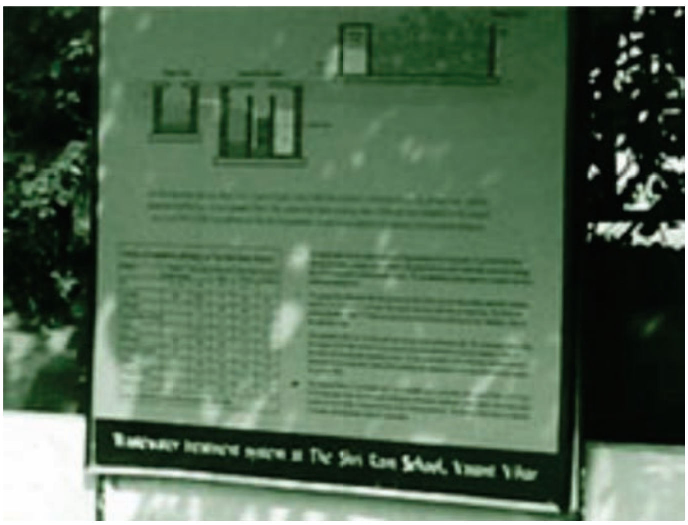

Figure 16

- The systems are not susceptible to effluent changes and are able to withstand shock loadings, while maintaining a consistent discharge quality.
- Reed beds are also cheap to run and maintain compared with established sewage systems.
- Meet the existing guidelines as well as permissible limits as per the standards.
- Being self regulated systems, they are simple to operate without chemical additives or complex electronic controls.
- They produce no sludge or other by-products that might incur additional costs of disposal.
- By investing in a reed bed treatment system, companies not only benefit from such advantages, but can also truly claim to be protecting the environment and bringing human activity into balance with nature.

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