Introduction: A History Lesson for the World, Artificial Wetlands for Wastewater Treatment (AWTS)

General:

Artificial Wetland Treatment Systems (AWTS) have been around for a long long time. Unfortunately, the large amounts of money provided by Federal and State governments in the United States back in the 1970's (typically 90% of treatment plant costs) discouraged communities from exploring alternative technologies like Artificial Wetlands. Engineering firms typically base their fees on a percent of construction costs, so that both the municipality and their consultants had strong incentives to spend a lot of money for "concrete and steel" systems that typically do only a "fair" job of treatment (i.e. 90% efficiency). The remaining contamination (typically 10% or more) is discharged to our streams under federal and state discharge permit programs. When it rains, most treatment plants perform more poorly, and more contamination enters the rivers.

With nearly 30 years of history and experience behind us many lessons have been learned, and many new problems now face small sewer districts:

1.) The old "concrete and steel" facilities are getting "tired", as their parts, pumps, concrete, and steel etc. deteriorate and corrode.
2.) Flow rates continually increase, overloading the older treatment plants and increasing the amount of biosolids that need to be dealt with.
3.) Financial assistance is hard to find, so that "users" typically must pay the cost of operation and upgrades.
4.) The costs of electricity, chemicals, fuel, labor, and other materials continue to tax the pocketbook and the environment.
5.) Very few people have ever considered the secondary pollution caused by "concrete and steel" facilities (e.g. air pollution from aerosols, diesel trucks hauling sludge, the use of fossil fuels to generate electricity, chlorinated hydrocarbons discharging to the rivers, etc, etc).

The simple truth is that pollution control technology causes pollution itself, so that the environmental costs and benefits of the technology need to also be evaluated.

For the past 30 years, other parts of the world have spent their money much more wisely. Where land was available thousands of facilities were constructed using what is often called "Alternative Technology". In general these systems:

1.) Minimize the need for electricity, chemicals, labor, and they produce less residuals;
2.) Utilize natural systems known to work well in nature;
3.) Are more "environmentally friendly". They often serve as wildlife habitat, and cleaner effluents can be recycled or used to recharge depleted groundwater resources or to irrigate forests and croplands.

4.) Cost a lot less to build and operate, and they produce an effluent far superior to any type of conventional treatment (i.e. at least 90% better than conventional systems).

For all the reasons mentioned, people are now asking:

1.) How do you build Artificial Wetlands?
2.) How do they work?
3.) How much do they cost?
4.) How long will they last?
5.) Will they work in cold climates?
6.) Do they smell?
7.) Are they safe?
8.) Why did the United States wait so long to “get smart” about wastewater treatment?

In the following paragraphs NEWS will attempt to answer some of the questions typically asked about Artificial Wetlands.

How are they built?

Each system must be designed for the specific wastewater to be treated, but in general, Artificial Wetland Treatment Systems all include the following:

1.) A liner to prevent groundwater infiltration.
2.) A media that wetland plants can grow in.
3.) Wetland plants the aerate the media where bacteria live and digest the waste.
4.) A minimum of valving and pipes to insure proper treatment times.

Free Water Surface Systems (FWS)

These systems typically emulate natural wetlands and they do a fine job of treating for nutrient removal or polishing secondary effluents. These lagoon like structures are easy to build, and actually increase the inventory of wetland acreage. In colder climates, however, or when wastewaters are more potent, the FWS systems are less effective. In Ecuador they would increase breeding grounds for mosquitoes where hospital wastes and waterborne disease organisms can be easily transmitted. It is the opinion of NEWS that a moratorium on all lagoons, oxidation ponds, and free water surface systems should be imposed throughout the country unless the wastewater is “pathogen free”.

Submerged Bed Systems (SBS)

These systems are the “work horses” of Artificial Wetland Technology, and they are equally attractive from an aesthetic point of view. There are no open waters, and limited activities like grazing small farm animals is possible on top of these “beds”. As with FWS systems, the SBS’s have a liner, a growth media, drains, and plants. The primary difference is that the wastewater being treated is hydraulically controlled in a way that eliminates “surface ponding”, and instead maintains a “watertable” just below the growth media surface (usually 2-4 inches). As such the plants grow hydroponically in the media while the wastewater slowly passes through the system. If desired, a SBS can actually produce “drinking water”! Much of the technology has been developed by NASA for astronauts living in “space stations”. In many cases the wetland plants can also be eaten by animals. This is especially true for the treatment of agricultural food processing and slaughterhouse wastewaters. In Ecuador, NEWS allows goats and sheep to graze on “german grass” growing in Rain Forest treatment systems. Submerged Bed Systems work much faster, use less land, and eliminate the possibility of insects and odor problems. In New England, the SBS also works better in the winter, because the natural insulation of snow, air, soil, and warm wastewater prevent freezing. During winter operation the SBS’s do operate about 25% more slowly, so NEWS typically designs them at least 25% larger than what would be needed for warm weather operation Several interesting articles regarding Artificial Wetland Treatment systems are appended.

How much do they cost?

A few general “rules of thumb” are as follows.

1) Properly operated a 2 m^2 SBS treatment area is needed per person. For domestic wastewater, the concentration of BOD_5 can be reduced from 250 mg/l to less than 5 mg/l with a treatment time of 3-5 days.
2) The cost of constructing an average treatment area can vary considerably depending on the site location and availability of materials, but generally the cost would not exceed $20/$m^2$ in most of Ecuador. NEWS is currently performing studies to evaluate the use of alternative construction materials and growth media’s such as recycled plastics, coconut fiber, coffee casks, etc. The use of these materials in place of conventional sand and gravel could reduce construction costs by as much as 50%.
3) The most important cost considerations are related to operation and maintenance. Generally SBS treatment units require little or no electricity, no chemicals, no pumps, and minimal operating and maintenance personnel. It is important, however, to realize that regular performance monitoring is essential for maximum operating efficiency. In Shushufindi, Ecuador NEWS has worked with the municipality to establish its own water quality laboratory. As such, Shushufindi will have a laboratory technician to monitor its several SBS treatment units on a daily basis.

How long will they last?

The permeability (Darcy’s k) of the growth media is always designed to have a k value that is at least 100x greater than the “long term acceptance rate (LTAR)” that develops with the formation of a “biological scum layer”. As an example, NEWS would expect that a coarse sand with a k value of 50 m/day would partially clog to a rate of 0.5 m/day within the first several years of operation. From that point on, the growth media will continue to process and treat wastewater for many decades. Because sand, gravel, liner material and PVC plumbing are virtually non-distructable, there is no finite life to a SBS unit. Logically, physical or chemical abuse, overloading, or the introduction of solids or toxic substances could destroy proper operational performance very quickly.

Do they work in cold climates?

Yes! Even though snow cover and freezing can occur at the surface, the SBS units themselves do not freeze. Plant root and bacterial metabolism do "slow down" during winter months, but NEWS compensates for this natural change by increasing the design area by about 25%.

Do they smell?

No! Even Red Beds used to dewater biosolids (sludge) operate odor free. All of the net biological processes involved are typically aerobic, producing end products of CO_2, H_2O, NO^3, etc. Providing that the systems does not turn anerobic from overloading, there is no reason to expect that anerobic odor conditions will ever develop.

Are they safe?

Some people have described SBS treatment units as "bullet proof". That is to say, they perform extremely well over a broad range of adverse conditions. Most importantly for tropical areas, the do not produce disease carrying mosquitoes. As previously mentioned, when properly designed they can provide for water reuse, animal grazing, food production, and even drinking water.

Why did the United States wait so long to "get smart"?

Unfortunately, engineers typically know very little about plant growth and their use for treatment. For this reason, conventional "concrete and steel" facilities were the typical technology of choice during the "Construction Grants Program" of the US-EPA. With that program now ended, and with government grants for wastewater treatment almost totally gone, municipalities are now faced with paying all of the construction, maintenance, and operational expenses. Considering that SBS units typically cost 50 – 75% less to construct, 75-90% less to operate and maintain, and that they produce an effluent of typically 75-90% cleaner, there is little wonder that many of the wastewater treatment decisions makers are now turning to Artificial Wetlands as the system of choice.

LIVING FILTERS

A LOW COST LANDFILL LEACHATE TREATMENT SYSTEM

A Brief History of Landfills

For many centuries, mankind has chosen to dispose of many of its various wastes by burying them in the ground. It was only several decades ago that attention began to focus on the environmental pollution that resulted from precipitation and groundwater infiltrating and passing through our buried wastes. The substance which forms when water passes through buried refuse is known as landfill leachate, and it is a most vile and noxious juice, highly toxic to most living organisms, and extremely difficult to treat.

Through the mid-seventies various scientists, including Dr. Lavigne, documented that leachate from landfills was contaminating surface and groundwater supplies. Eventually regulations were passed requiring that landfills be lined so that the leachate could be collected and treated.

Today leachate from many landfills is collected and treated at either existing sewage treatment plants or at on-site leachate treatment plants. Unfortunately, the costs of constructing and operating the plants, and especially of operating the mechanical oxidation equipment, make treating leachate with conventional methods an expensive process. Constructed wetlands now offer an alternative, low-cost, low-maintenance, low-energy method for effectively treating landfill leachates.

A Brief History of Constructed Wetlands

Natural wetland systems have developed unique purification processes through millions of years of evolution. Scientists recognized the potential of wetland systems to treat wastewater many years ago and the evaluation of various wetland plants and microorganisms has been the focus of various research projects for nearly 40 years.

In the late seventies, Dr. Lavigne's first constructed wetland treatment system was successfully developed at a small, private landfill in Barre, Massachusetts. The system, one of the first of its kind, utilized treatment lagoons seeded with duckweed. The system was subsequently upscaled to meet the leachate treatment requirements for a 35-acre landfill in Lowell, Massachusetts. The system treated leachate very well, but unfortunately the open lagoons gave off a rogue smell and became a breeding ground for mosquitoes.

With a goal to eliminate the drawbacks of open lagoons and possibly increase treatment effectiveness, Dr. Lavigne returned to the laboratory where, through the eighties, he developed the Peat Moss-Reed Canarygrass Leachate Treatment System (U.S. Pat. #4,995,969). The new system not only eliminated the smell and mosquito problems but, due to an enormous increase in surface area for microbial growth, treatment time was reduced by over ninety percent.

New England Waste Systems now offers these Constructed Wetland Living Filters for treating a broad spectrum of municipal and industrial wastestreams.

What is a Constructed Wetland Living Filter?

A Constructed Wetland Living Filter is a manmade wastewater treatment system constructed so as to emulate and maximize the natural biochemical purification processes known to occur in natural wetland systems.

In a natural wetland, aquatic plants pump oxygen from the air down to their roots in order to survive in their saturated habitat. The thin layer of oxygen that covers the plant's roots supports a diverse population of aerobic microbes, which digest organic molecules and in turn release carbon dioxide and water.

In a Constructed Wetland Living Filter, the effectiveness of microbial digestion is increased tremendously by creating highly favorable microbial growth conditions using a peat moss based growth media planted with the aquatic species Reed Canarygrass.

What is landfill leachate?

Landfill leachate is the fluid that flows from the base of a landfill when water percolates through the layers of buried refuse. The water mixes with the various organic acids produced by the anaerobic bacteria that live deep within the landfill. The acidic mixture then reduces metals within the refuse and allows them to become mobile metal ions. The resultant mixture is a rich soup of small and large organic molecules in an acidic aqueous solution with generally high concentrations of heavy metals.

It is the complex chemical composition of leachate and its high heavy metals concentrations that make landfill leachate both very difficult and expensive to treat using conventional methods.

How does the Constructed Wetland Living Filter treat landfill leachate?

Constructed Wetland Living Filters use nature's sanitation workers, millions of microorganisms, to digest the complex organic molecules in landfill leachate. The peat moss growth media has a tremendous surface area to volume ratio and provides innumerable "homes" where the bacteria can live and do their work. The Reed Canarygrass develops an extensive root network throughout the peat moss and thereby provides the oxygen required by the aerobic bacteria to digest organic molecules and form carbon dioxide and water.

Additionally, both the peat moss and the Reed Canarygrass are excellent adsorbers of heavy metal ions. The combination of digestion and cation adsorption that takes place in a Constructed Wetlands Living Filter provides a 99% reduction in TOC, BOD and heavy metal concentrations with residence times as short as twenty-four hours.

Why are Constructed Wetland Living Filters "low cost" relative to conventional leachate treatment methods?

Properly designed, constructed, and operated, Living Filters will provide highly effective waste stream purification in a system that requires virtually no energy input, needs little maintenance, uses almost no manual labor, and can be constructed at a fraction of the cost of conventional treatment plants. A general schematic of a Constructed Wetland Living Filter is shown in Figure 1.

In contrast, conventional treatment plants generally use large amounts of electricity, require considerable maintenance, chemicals, and labor, and often have tremendous construction costs.

ARTIFICIAL WETLAND TREATMENT TECHNOLOGY AND IT'S USE IN THE AMAZON RAIN FORESTS OF ECUADOR

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ABSTRACT

The construction of conventional "concrete and steel" wastewater treatment facilities is clearly not feasible for many developing countries where conventional materials and financial resources are not available. Nonetheless these areas are growing rapidly both in numbers of inhabitants and industrial development. This is especially true for the rain forests of South America and the Amazon River headwaters. Over the past 20 years US and other international petroleum companies have been rapidly extracting "crude oil" from the Amazon Region. This has required the construction of access roads for pipelines across the Andes Mountains. Many poor people seeking employment with oil companies have followed, bringing their families and all of their worldly possessions. Oil towns such as Shushufindi, Coca, and Lago Agria have expanded in size and number very rapidly with population doubling times often as short as five years. With this bludgeoning growth have come the problems of water supply, wastewater management and solid waste disposal. As is true for most of South America the accepted method of wastewater disposal has been direct discharge to either rivers or associated wetland areas. Only recently with assistance from the World Bank has Ecuador begun to deal with its wastewater problems. In Shushufindi, Ecuador, the municipality of 10,000 people has recently constructed the Country's first Artificial Wetland (1200 m^2) to treat the residual waters emitting from the local slaughterhouse. Previously the wastewater discharged directly into the Shushufindi River as does the municipalities 2 million liters/day of domestic sewage. Unfortunately down stream indigenous tribes such as the Secoya have been seriously impacted by these up-stream activities. The slaughterhouse wastewater treatment facility was completely constructed using local materials and labor, and is currently discharging an effluent that is "near" drinking water quality. A second much larger facility (2 hectares) is under construction to treat Shushufindi's 2000 m^3/day of domestic sewage. The design, construction and operational performance of the Shushufindi slaughterhouse facility, however is the focal point of this paper.

KEYWORDS

Artificial Wetland; Submerged Bed System; Slaughterhouse Waste.

INTRODUCTION

The Municipality of Shushufindi is the governmental center of a County with the same name in the Ecuadorian Amazon. Its rapid growth over the past three decades has been primarily due to expanding oil exploitation and colonization of highland settlers in the immediate area. As is often the case in the new frontier setting, little or no planning accompanied the physical and demographic expansion of the Municipality of Shushufindi. Consequently, most of the densely populated areas have evolved without a sanitary wastewater infrastructure.

In 1997 the Municipality of Shushufindi's waterways were in need of treatment. Typically residential and commercial sewage discharge to the nearest ditch, which leads to or directly into a large wetland at the northern end of town. This wetland of 10+ hectares is hydraulically connected to the Shushufindi River via a small brook. Additionally, the municipal slaughterhouse was removing water from the river for processing and dumping all waste back into the river. Waste-laden waters throughout the community had become prime breeding grounds for mosquitoes and other potential vectors of disease, constituting a significant public health threat. Several years ago a small grant from the Texaco Oil Company facilitated the construction of a new sewage collection system for the more densely populated streets of Shushufindi. However, the new sewer lines discharge directly into the wetland describe above. Residents living in the peripheral part of town and the *Secoya* settlement downstream use the river for laundry purposes, bathing and swimming. Some people without access to a well even drink from the river. With a population quickly approaching 10,000 people, it is estimated that some 2 million liters per day of raw sewage will soon be discharging into the Shushufindi River unless a treatment facility is rapidly constructed.

For many decades natural systems for wastewater treatment have been the method of choice where land is inexpensive, capital resources are limited, and where a high quality effluent is desired. Finding these conditions in Shushufindi an Artificial Wetland System (AWTS) or "Pantano Artificial" was proposed as the best solution for wastewater treatment. Within the rain forest of Ecuador ample natural materials exist. Growth media such as sand and gravel are plentiful along the riverbanks. Clay for natural liners dominates the soil. *Echinochloa polystachya* "German Grass" and *Panicum maxium* "Saboya" currently dominate the wetland areas, and their anatomy (i.e. aerenchyma) make them excellent species for wastewater treatment. Additional reasons to choose an AWTS are the lack of construction capital, and the lack of technical familarity necessary for conventional concrete and steel (e.g. oxidation ponds, activated sludge, etc.) treatment systems.A proposal to build an Artificial Wetland Treatment system for the sanitary sewage of the municipality of Shushufindi, Ecuador was funded by the World Bank through the Ministry of the Environment. While contracts and details were being finalized it was decided that a "pilot" size project would demonstrate the technology, and serve as a training course for construction of the large municipal system.

The Shushufindi municipal slaughterhouse was chosen as the pilot project for Artificial Wetland Technology in the rain forest. Adequate municipally owned land was available, construction materials (sand, gravel, and clay) were available from the municipality or onsite, municipal workers could be trained in construction techniques on the smaller project, and a small grant was obtained from the World Bank through the Ministry of the Environment to purchase pipes, valves, etc.

METHODS

For the Artificial Wetland Systems in Shushufindi, Ecuador, the top loading method of operation has been the system of choice. Series operation of 2 “top loading” submerged bed wetland cells was chosen to provide the best quality effluent, with the first bed used for “roughing” and the second for “polishing”.

System Components

The system consists of two top loading beds and two concrete settling tanks. Theses tanks were designed to process approximately 20m^3/day of wastewater. The tanks are connected in series, and collectively provide approximately 2 days of theoretical detention time. This determination is somewhat inaccurate because the slaughterhouse operates only in the afternoon and the daily discharged is concentrated over several hours.

Each tank is constructed with an inlet and outlet “T”. The purpose of the inlet “T” is to slow down the velocity of the waste water entering the tank. This is important to prevent mixing and stirring in the tank. The more tranquil the flow, the better the settling of solids. The purpose of the outlet “T” is to prevent floating materials from leaving the settling tanks and possibly clogging the artificial wetland cells. The outlet “T” extends to a depth of 50 cm in each tank. This represents the maximum depth to which floating materials can accumulate without leaving the tank through the outlet pipe. Some solids will also settle to the bottom and accumulate over time. The maximum permissible depth for settling solids is approximately 1 meter.

Solids Disposal The floating surface solids are primarily animal feces. As such they make an excellent fertilizer for plants or gardens. If practical uses for the surface solids cannot be implemented the materials can be landfilled with the other municipal solid waste. A small reed bed has been constructed at the slaughterhouse to treat the settled liquid sludge with underdrain waters directed to the primary Artificial Wetland cell for treatment. An alternative disposal is to process the slaughterhouse sludge at the municipal Artificial Wetland System when construction of that facility is completed.

Insect and Odor Control The covers to each settling tank are maintained in an insect proof condition by tightly sealing seams and contact points between the steel cover and concrete tanks. Hinged covers which close tightly to prevent insect entrance have been installed at each of the 4 “T”s. While a problem has not yet developed, if it becomes necessary to vent the two settling tanks, a vent stack will be installed in the influent line.

Construction and Sampling

The first treatment cell of SBTS for the Shushufindi municipal slaughterhouse was planted February 6, 1999. Initial samples of influent and effluent quality were taken in June 1999. During June 1999 the second treatment cell was planted, and samples were taken from both cells in July 1999. Sampling was repeated in January 2000. All samples were analyzed for pH, EC, COD, NO_3, NH_4, and PO_4. The first set of samples (June, 1999) was analyzed for DO, while the later sets (July, 1999 and January 2000) were analyzed for BOD_5. Samples taken during 1999 were analyzed for nitrite ($NO_{2)}$) concentration as well as nitrate (NO_3) and ammonia (NH_4) concentrations. Analysis of the January 2000 samples includes total coliform, total and suspended solids, and potassium (K) concentrations as well as the parameters measured on earlier sampling dates. Influent and effluent samples, as well as a sample of the Shushufindi River were sent to the Analytical Laboratory in Coca, Ecuador and analyzed using industry standard methods (Standard Methods for the Examination of Water and Wastewater, 1995).

Design

Submerged Bed Treatment Systems (SBTS) are typically constructed 70-80 cm deep, with some type of liner material and with dikes high enough to contain the systems interior components as well as preventing surface waters from entering during storm and associated run-off events.

Typical “end loading” SBTS require the wastewater being treated to travel the full length of the bed. These systems only perform well when there are essentially no suspended solids in the wastestream. If suspended solids exist, or if dense bacterial growth at the headworks are not compensated for, the systems are prone to clogging. Once hydraulic conductivity rates at the inlet end fall below application rates to the bed, wastewater surfaces and flows overland. When this occurs treatment is significantly reduced, and the system is in failure. A second limiting factor of an “end loading” SBTS is the minimal cross sectional area available for loading (i.e. width x depth). By inspection of Darcy’s Law for uni-directional flow (Eq.1), it is clearly evident that Q for a SBTS is reduced proportionately if the cross sectional area (A_{xs}) is minimal, or if clogging reduces the coefficient of permeability (K). The gradient (differential head/length of porous media, (H/L)) is also typically small for end loading SBTS’s due to the large aspect ratio of these units.

$$Q = KA_{xs}H/L \qquad \text{Eq. 1.}$$

An alternative operational modification to the SBTS is illustrated in Figures 1 and 2. For "toploading" systems H/L is typically unity, clogging is reduced due to the large surface area available for loading (i.e. greater K), and the cross sectional area A_{xs} becomes the surface area of the bed instead of the end area. Required detention times are maintained and controlled by an "outlet box" which is designed to provide variable heads ranging from 0 to unity.

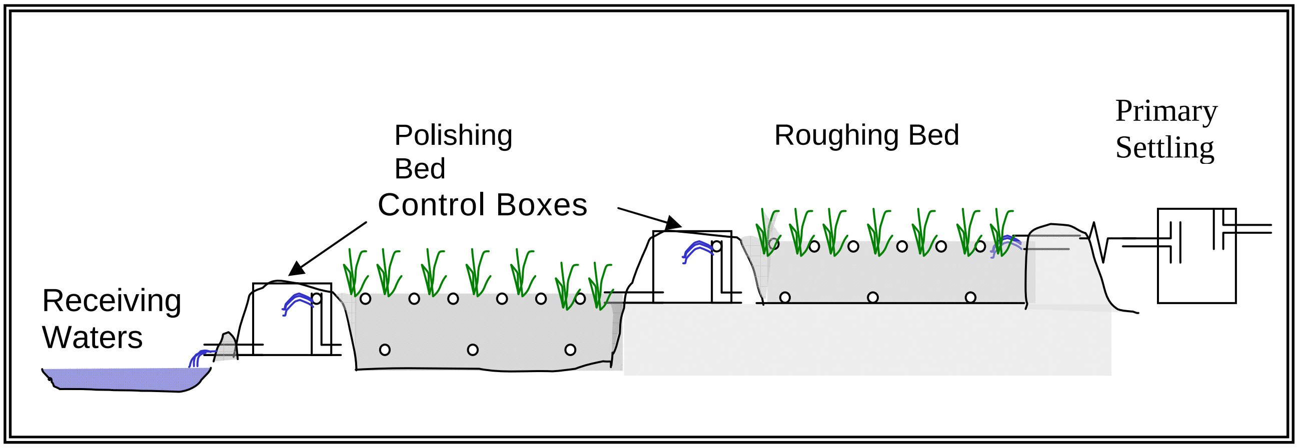

Figure 1. Artificial Wetland Treatment System, Cross Sectional View.

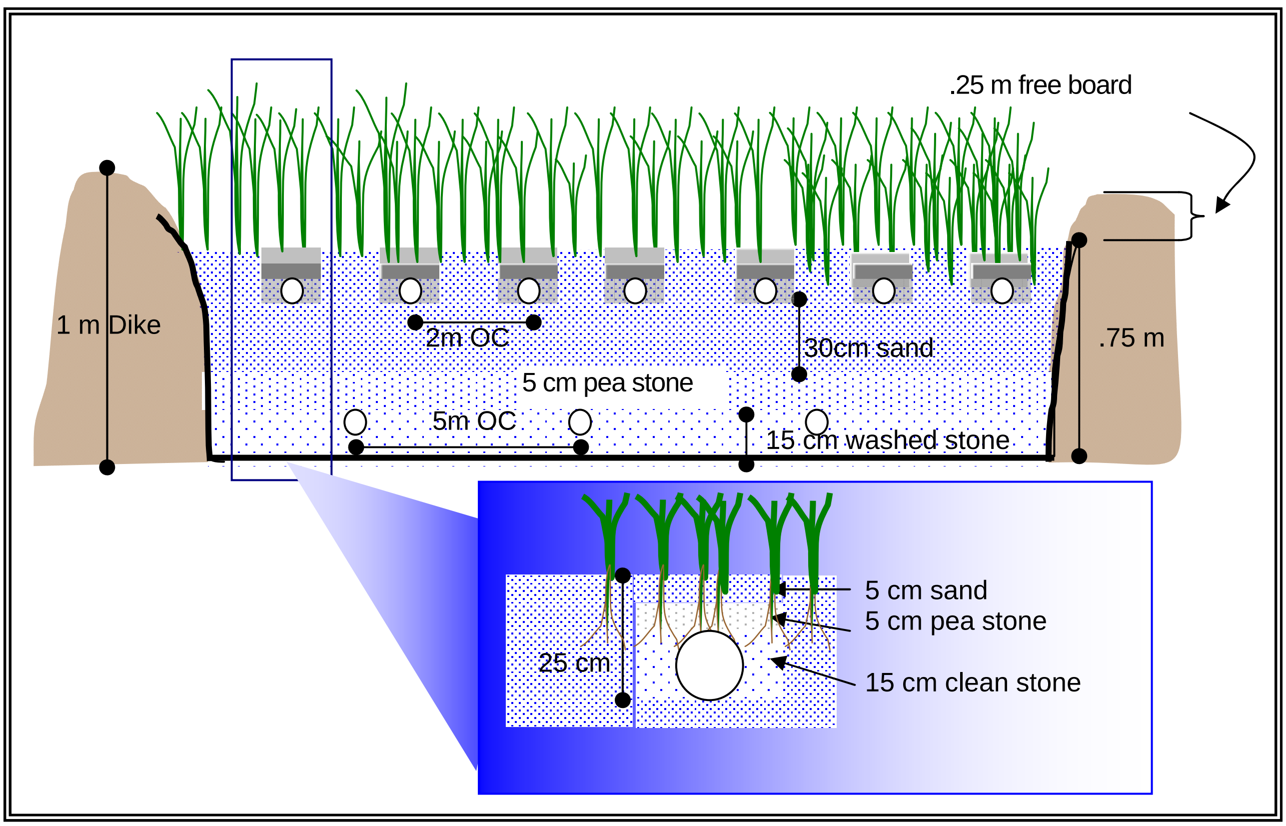

Figure 2. Single bed detail.

RESULTS AND DISCUSSION

Most wastewater treatment processes are either aerobic or anaerobic. In a SBTS, however, both environments can exist within close proximity to each other. Excess oxygen gas diffuses out of the root creating an aerobic annulus around it. In this area, biological and chemical processes will be typically aerobic. At some distance away from the root, oxygen concentrations will reduce to zero due to the demand created by biochemical aerobic activity. Biological and chemical processes in this outer zone will remain anaerobic in nature until another “root zone” is encountered. The diameter of the oxygen rich annulus will be controlled by the degree of the oxygen demanding forces at work. When plants and roots are dense and deep, aeration is at a maximum. If the wastewater strength is mild, aerobic processes will dominate the system. The initial negative aspect of this condition is reduced denitrification. When plants and root depths are few and shallow such as during the start up phase of an artificial wetland cell, anaerobic processes will predominate. Reduced metals will become mobile under these conditions, and BOD levels in the effluent will typically be greater (Figures 3 and 4).

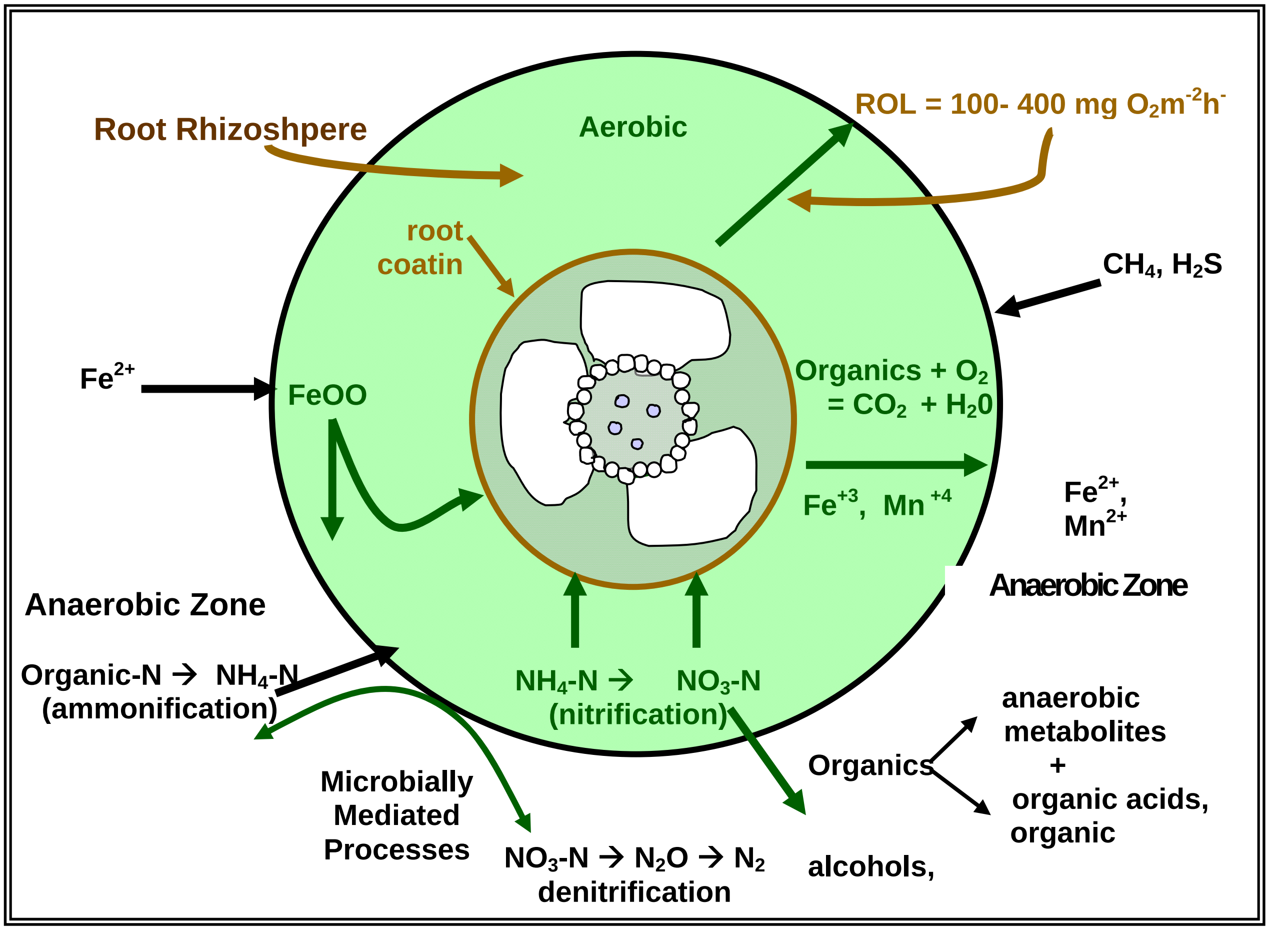

Figure 3. Dynamics of the root-growth media interface (adapted from Good and Patrick)

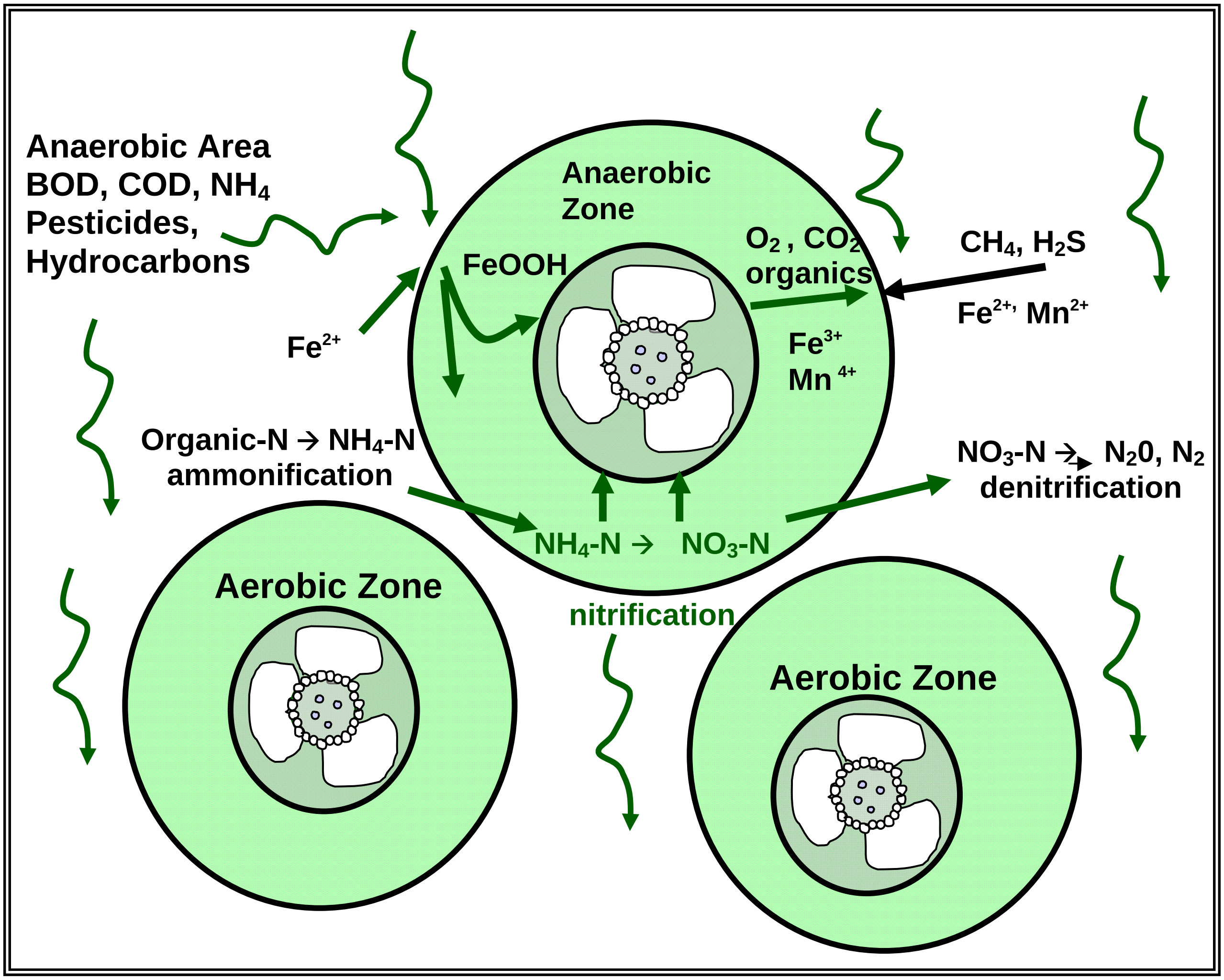

Figure 4. Dynamics of multiple root-growth media interfaces (adapted from Good and Patrick).

One of the primary differences between SBTS units and other wetland treatment types is the large surface area associated with the growth media. The media not only sieves solids, and supports fixed bacterial films but it also enhances removal of contaminants such as orthophosphates by a variety of surface adsorption and complexation processes (Table 1). Most plants are know to absorb essentially any material that can permeate the root cell membrane and wall. In the case of nutrients, the materials are used for growth as well as being translocated and stored in various parts of the plant (roots, stems, or leaves).

It is important to realize that dissolved oxygen measurements (Table 1) of the effluent represent an "integrated measurement" for the entire SBTS. An effluent concentration of 2 mg/l (typical for a properly operating SBTS), should not be interpreted as indicating a totally aerobic environment within the bed. More realistically the value is an “integration” of many aerobic and anaerobic sites. This holistic conclusion is based on changes in wastewater constituent concentrations that are clearly linked to both aerobic and anaerobic processes (e.g. nitrification/denitrification).

Table 1. Influent and effluent concentrations of wastewater parameters from the Shushufindi municipal slaughterhouse for three sampling dates during the first year of operation.

Sample	pH	EC µS/cm	COD mg/l	O_2 mg/l	NO_2 mg/l	NO_3 mg/l	NH_4 mg/l	PO_4 mg/l
June 21, 1999								
Settling Tank 2	5.9	352	187	0.1				
Bed 1 Effluent	6.3			0.3	0.11	3.94	0.12	1.23
Bed 2 Effluent	5.6	425	<5	0.94				
River Shushufindi	5.8	538	<5	4.4	0.37	1.98		
July 29, 1999								
Sample	pH	EC µS/cm	COD mg/l	BOD_5 mg/l	NO_2 mg/l	NO_3 mg/l	NH_4 mg/l	PO_4 mg/l
Settling Tank 2	6.41	628	396	185	0.1	1.0	30	8.9
Bed 1 Effluent	6.65	5.91	26	24	0.07	1.2	3.11	1.6
Bed 2 Effluent	6.97	533	<5	<5	0.06	1.8	0.79	0.1
River Shushufindi	7.44	69.1	50	<5	0.11	2.7	0.11	0.1
January 8, 2000								
Settling Tank 2	6.7	513	301	288	9.40	0.18	27.68	2.21
Bed 1 Effluent	6.7	263	72	27	6.62	0.76	18.02	0.90
Bed 2 Effluent	6.5	226	11	3	4.84	7.22	9.43	<dl
River Shushufindi	7.1	45.3	4	0	1.43	0.88	0.01	<dl

Settling tanks typically remove about 65% of the suspended solids in wastewater. The remaining 35% (both organic and inorganic) will naturally sieve out generally at the stone/sand interface in the distribution lines of a SBTS. The formation of a biological "scum layer" can also be anticipated at the same interface. The natural sieving that occurs through this "Schmutzdecke" like material greatly enhances treatment performance. This is also the primary location for bacterial and other microscopic organism removal (Tables 2 and 3).

Table 2. Fecal Coliform counts from the Shushufindi municipal slaughterhouse for three sampling dates during the first year of operation.

Sample	Fecal Coliform # col/100 ml		
	June 21, 1999	July 29, 1999	January 8, 2000
Settling Tank 2	202,000	2400	121,000
Bed 1 Effluent		585	48,000
Bed 2 Effluent	34	262	6,000
River Shushufindi		917	600

Table 3. Total and fecal coliform counts, total solids and suspended solids from the Shushufindi municipal slaughterhouse January 8, 2000.

Sample	Total Coliform # col/100 ml	Fecal Coliform # col/100 ml	Total Solids mg/l	Suspended Solids (NTU)
Settling Tank 2	385,000	121,000	377	106
Bed 1 Effluent	204,000	48,000	172	21
Bed 2 Effluent	22,000	6,000	14	1.5
River Shushufindi	2000	600	37	17

CONCLUSIONS

Several of the benefits of SBS are i) no standing water nor mosquito breeding; ii) no odors, iii) aerobic and anaerobic processes occurring simultaneously in the respective microsites, iv) maximum conversion efficiency due to the large microbial biomass associated with the rhizosphere, and v) excellent sieving of smaller particulates.

It should be remembered that Shushufindi represents a unique paradigm for the rest of the world to emulate. To the best of our knowledge it is the only wastewater treatment facility built by the “stakeholders” directly. This project demonstrates that a wastewater facility can be low tech, low cost and completely sustainable; virtually independent of chemical and electrical needs. The errors and delays to date have not been major ones, and the educational values in preparation for construction of the 4-hectare facility are immeasurable. If local labor and natural materials can be used by other municipalities to build and operate their environmental infrastructure, there is hope that the waters of the Ecuadorian Rain Forest and those of the rest of the developing world may someday run pure again.

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REED BEDS

A LOW COST SLUDGE TREATMENT SYSTEM

What the operators say...

"It can be used year-round and is maintenance-free."

-Richard Smith,
Saxton's River, VT

" The cost is going to be significantly less. The sludge will be dewatered without any energy input or any man-hour input. Whereas with a drying bed, you have time requirements for both taking it off and putting it on the beds. I don't have enough time to get everything done that I need to do right now, and I didn't want another dewatering job that would take up a lot of man-hours that we didn't have available anyway."

-Dan Florio
Shelburne Falls, MA

" The plant's getting old, many of the technologies we're using now are outdated, and it's a major challenge to upgrade the facility to today's technologies. Vacuum filtration is the oldest technology we have at the plant, and it isn't working very well to say the least. Also three years ago we lost our landfill for sludge disposal. So we were faced with the problem of having no place to get rid of our sludge, and also with dewatering it. The Reed Bed idea really caught my interest because it took care of both of our problems, dewatering and disposal."

-Tim Henry
Ipswich, MA

INTRODUCTION

What is a Reed Bed ?

A Reed Bed is basically a conventional sludge drying bed planted with reeds *(Phragmites communis)*. Unlike a conventional bed, the Reed Bed does not have to be scraped off before another layer of sludge is added. Sludge is applied to the Reed Bed every two weeks year-round for ten years (see Fig. 2). Over the life-cycle of a Reed Bed, the initial sludge volume will be reduced from 95% to 98%, through drainage, evapo-transpiration, plant uptake, and microbial decomposition. The final product is a well-decomposed, stabilized, humus-like residue suitable for land-application.

What are the benefits of using a Reed Bed?

- Volume reduction of better than 95%
- Year-round operation
- Low capital cost: The initial cost can be comparable to the cost of a belt filter press, but unlike a filter press, a Reed Bed is essentially permanent; it can last through many 10 year sludge application cycles with minor repairs.
- Low operating cost: A Reed Bed has minimal labor and energy requirements, and few moving parts to replace.
- 10-year application and storage cycle before disposal of dewatered, stabilized, mineralized, low-solids content, microbe-rich sludge residue.
- Odor-free operation.

How does a Reed Bed work?

In conventional sand drying beds, dried sludge forms an impermeable layer that prevents the application of more sludge until the layer is scraped off. In a Reed Bed, a dense mat of roots and rhizomes provides channels for water to flow down to the underdrains. In warm weather, the plants also take up some of the water and nutrients for their own needs. Oxygen is carried from the leaves through the roots, to microbial populations, which in turn help to stabilize and mineralize the sludge.

How does a Reed Bed function in winter?

In winter, although plant growth has stopped, root growth continues through the new sludge that is added. The freezing and thawing of the sludge in winter also serves to turn it into a more friable material which drains easily. Sludge is applied in winter regardless of weather or snow cover.

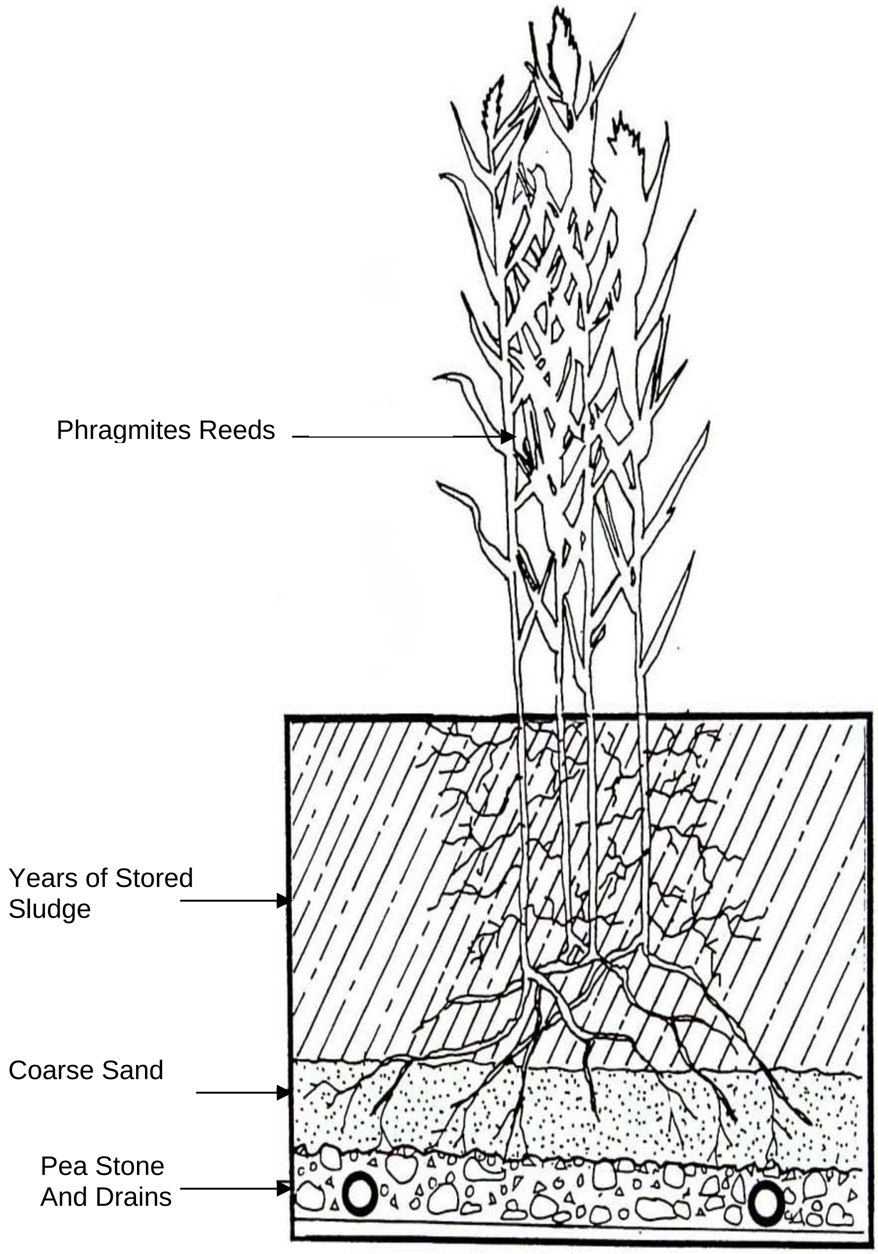


Figure 1. Reed Bed cross sectional view.

What is special about the reeds?

The roots of the Phragmites reed grow upward and outward: as a new sludge layer is applied, roots grow from nodes on the stem and penetrate the new layer. The Phragmites Reed is a perennial grass that grows worldwide, in climactic conditions varying from wet lowland areas to elevations to 18,000 feet. The reeds are used by Europeans for roofing, thatch, and basketry. In the USA Phragmites are a high-priced ornamental and in the Peoples Republic of China Phragmites are used to make the highest grade paper they have.

How much land is needed for a bed?

One square foot of bed treats approximately 25 to 75 gallons of sludge per year of aerobically digested sludge, and approximately 14 to 41 gallons per year of anaerobically digested sludge.

How long does it take to fill up?

The beds are emptied after 6-10 years. After the sludge is removed, the reeds will grow back from the remaining rhizomes, and the next cycle of sludge application can begin.

How much does it cost?

Cost will vary depending on site conditions and existing facilities. If a sand drying bed is already in place, retrofitting the bed is a relatively easy task and the cost will therefore be lower. For new beds, assuming satisfactory site conditions, average cost for the design and installation of a Reed Bed system will be close to $10.00 to $12.00 per square foot.

Can old sludge drying beds be converted?

The beds are constructed using a variety of methods depending upon the site conditions, or may even be converted existing drying beds. Earth berms are a common and relatively inexpensive method of construction if the site permits. Concrete or wood retaining walls can also be used effectively for the construction of reed beds. The beds are lined with heavy vinyl and provided with underdrains to return leachate to the treatment plant. <u>Greenhouses are not only unnecessary, but should not be used with reed beds.</u>

What if the plant's operating program calls for sludge wasting more often than every two weeks?

The system can be designed with sections that receive sludge on a rotating basis. Each section is flooded only every two weeks, but the operator can waste sludge once a week or more often, to one section at a time.

How can a Reed Bed be used with a lagoon system?

A Reed Bed system can be used effectively with an aerated wastewater lagoon. Normally, a lagoon needs to be taken out of service ad drained to remove the accumulated sludge. A system in Caribou, Maine pumps sludge from a lagoon with a floating pump, on a regular basis during the warmer months. The sludge is then applied directly to a Reed Bed. This system completely eliminates the need to take the lagoon out of service every eight to ten years.

What if a regional composting facility is built?

Composting systems cannot take liquid sludge. Reed Beds can dewater sludge to better than 95%, much more cheaply than belt filter presses. Installing a Reed Bed now can ensure up to ten years of sludge storage with a dewatered final product that can be composted, if desired.

MAINTENANCE

What will a reed system add to the daily work-load of an operator?

Not much. A Reed Bed system requires the attention of the plant operator for a short period on a schedule dictated by the system design, typically an hour or two a week or every other week. Applying sludge to the bed involves no more than opening a valve, turning on a pump, and then turning the valve off when the loading is finished. Once a year, in winter, the annual reed growth is cut back. The volume of reeds annually is approximately 50 bales/acre.

What common problems do operators face in managing reed beds?

Aphid infestation can slow the establishment of a healthy stand of reeds during the start-up period. Both biological and chemical controls have been successfully used to control aphid populations. An established bed can function very nicely with moderate aphid infestation.

What if the bed is overloaded by accident?

There is no treatment plant in the world that can always stick to its loading guidelines. Operators live in the real world. There will be times in a ten-year loading period when equipment will fail, and the operator will be faced with the choice of wasting sludge in the river, or on the Reed Bed. It is possible to get away with a rare overload or the application of undigested or sludge to a well established bed, although with reduced effectiveness. In the worst case of overloading we know of, the bed continued to function with dewatering and solids reduction of 93%.

What if the plants die?

Plants have died back when large quantities of undigested sludge were applied to a Reed Bed. System performance was affected, but dewatering and solids reduction continued. Just as in winter, established root systems continue to serve as channels for water. We are not saying a bed with dead reeds is desirable, but that in the rare event that there is an accident that causes a massive die-off, all is not lost.

Does a Reed Bed produce odors?

Reed beds are odor-free because the sludge is kept aerobic. Oxygen can penetrate the sludge as the water flows through, and also from the plants themselves, from the upper parts to the roots. Odor problems have only been associated with the application of undigested sludge. At a number of waste treatment facilities using reed beds, there are houses close by. In Beverly, New Jersey, numerous complaints were made about odors before the reed beds went in; such complaints are now nonexistent. At Winter Harbor, Maine, a house abuts the treatment plant fence; there have no complaints here.

SLUDGE REMOVAL

Is the sludge removed from the Reed Bed suitable for land application?

This will depend primarily upon **heavy metal concentration.** The reed system, like all processes that reduce the organic content of sludge (digestion, incineration and composting), causes the heavy metal concentration in the sludge to rise as it eliminates the organic material that dilutes the metals.

A Reed Bed can reduce the volatile solids in the sludge from 70% to 20%, reducing the volume of total solids by 50%. Therefore, the maximum concentration of heavy metals in the residual sludge would be double the concentration in the applied sludge. Similar concentrations would be seen with composting, if it weren't for the diluting effect of the addition of bulking agents.

However, not all of the metals in the sludge will remain in the bed. The reeds themselves will take up some metals from the sludge. An Army Corps of Engineers study found a 60% reduction of zinc and a 30% reduction of cadmium by the plants in a Reed Bed. In addition, since the Reed Beds are out in the open, they are subject to rain and snow, which leach out some of the metals from the beds, which then drain away in the leachate.

If the Reed Bed residue is not suitable for land application because of heavy metal concentrations, it will still be suitable to be mixed with compost, or sawdust, shavings, leaves or other suitable organic waste to bring the heavy metal concentrations to acceptable levels.

A second concern related to land application of Reed Bed residue has to do with the potential for **spreading the Phragmites reed.** The roots and rhizomes can be sifted out before land application, and the application of the sludge to wet areas can be avoided.

How will the bed be emptied?

The sludge can be taken off with a large backhoe with a 4 ft. trenching bucket. The sludge is scraped off, loaded into a truck, then disposed of at an appropriate site.

What happens to the bed after the sludge is removed?

After the sludge residue is removed, a thin layer of fresh sand is added, and the reeds are allowed to regenerate from the remaining rhizomes. The bed is a permanent installation, and will continue to function for many 10 year application cycles.

REED BED OPERATING MANUAL

Introduction

The Reed Bed System was developed in West Germany over 40 years ago by Dr. Kathe Seidel at the Max Plank Institute. During the past 10 years there have been over 100 installations in the United States. Most of these installations are used to de-water wastewater treatment plant biosolids.

The system is similar to conventional sand drying bed technology with the addition of the common reed *Phragmites communis*. The addition of plants to the sand beds allows for the long- term build up of sludge thus eliminating the need to clean the beds between sludge loadings. The plants provide pathways for drainage along their roots, utilize water for growth during the growing season, and help mineralize the sludge, with the assistance of bacteria, which exist in a symbiotic relationship with the plant. The bacteria derive oxygen from the plants and provide the plants with essential nutrients. By designing sidewalls 4-5 feet high the liquid sludge can be applied during the winter months even though there is reduced drainage due to freezing. The 3-4 foot freeboard also allows for the accumulation of sludge in the beds for 7 - 10 years before the sludge must be removed, at which time the sludge is analyzed and final disposal options can be determined.

Start-up

After planting, and for the first full year of operation, the beds should be loaded at about half the normal loading rate (i.e. 3 inches once a month). These conservative loadings allow the root system to become fully established throughout the bed. These loadings may occasionally need to be supplemented with plant effluent watering to prevent plant wilting during dry periods. It is very important that the sand remain moist at all times during the start-up phase. Remember, wetland plants need to be wet. **It is not recommended** that the extra water needed be supplied by increasing the sludge loadings. Experience has shown that this can badly stress or even kill off the young plants.

Following the first year of start up each bed should be loaded every other week with no more than 3" of sludge. If you have multiple beds, then you may waste sludge weekly by alternating the beds.

Figure 2. Phragmites shoots emerging from dried sludge.

Normal Operation

The start-up phase will take one to two years depending on plant growth and the time of year when the bed is planted. If there is vigorous reed growth throughout the bed the start-up phase can be shortened and normal loadings may begin earlier. Normal operation allows for the application of 32 - 4" of sludge per application. A normal application rate is once **every other week.**

On an annual basis (during the late fall to early winter after the reeds have turned brown), it will be necessary to cut the reeds to within 12" of the sludge surface. The cut material needs to be removed from the bed to prevent the accumulation of plant debris and to provide room for new growth in the spring. The cutting is done with either hedge clippers or weed trimmers and is most easily accomplished after the sludge has frozen. If the beds do not freeze it will still be necessary to cut and remove the reed stocks. The harvested plant material can be burned or shredded and composted. Small plastic snowshoes may be helpful when trimming non-frozen beds.

Figure 3. Reed Bed following annual trimming.

Monitoring

A logbook should be kept to document Reed Bed operation and should include the following:

Date of all loadings.
Operators initials.
Amount of sludge being applied.*
Percent total solids of the sludge applied.*
Percent volatile solids of the sludge being applied.*
Observations of plant growth.
Verification of leachate drainage.
Any maintenance performed and any other relevant observations.

* Information regarding percent solids and percent volatile solids is used to verify proper sludge condition after digestion, which greatly affects sludge loading rates. Loading rates are based on 2% solids concentration, and 70% or less volatile solids concentrations. If there are problems with reed growth, verify that the percent solids and volatile solids are within acceptable range. If they are not, it may be necessary to reduce application rates or to modify the digestion process.

Sludge Removal

With proper operation the reed bed should not require any sludge removal for 7 - 10 years if 4-5 feet of freeboard is provided in the bed design. When the depth of the dried sludge gets to within one foot of the top of the wall, the Reed Bed should be taken out of service, dried, and cleaned.

Any bed to be cleaned should not have sludge applied after plant growth has started in the spring. The bed should be allowed to dry to the point that the reeds wilt from lack of water. During this time, core samples should be taken and sent out for metals analysis. Based on the results of these analyses a determination as to the final disposal of the sludge can be made. Options include additional composting, land application and landfilling.

The bed may be excavated using a backhoe, front-end loader (Bobcat) or hand labor. Care must be taken to avoid damage to the bed liner (plastic, clay, etc.) New sand should be added to replace any sand removed with the sludge. It is also prudent to replant the bed even though much of the original rootstock will remain.

Figure 3. Sludge removed from Reed Bed following many years of operation.

Other Considerations

Occasionally we discover problems at some Reed Bed installations due to operational errors that are easily avoided.

A common problem is overloading of the beds. When an operator has limited sludge storage capability, there is a strong tendency to apply as much sludge as the treatment facility is producing. “I had to get rid of it somewhere” is a explanation we often hear. If the treatment plant is producing more sludge than can be applied to the reed bed, then immediate notification of the engineer is recommended so that alternate plans can be developed based on the loading rates specified in this manual.

Summer time operation of the reed beds requires regular attention to plant growth to assure that the reeds are **getting enough moisture**. If the sludge application rate is not enough to keep the sand moist, then the nutrient and oxygen rich plant effluent should be applied between sludge loadings. This is especially true during the first year. Observing potential problems early will help avoid larger problems later.

Avoid the use of any herbicides within 200 feet of the reed beds for obvious reasons.

Aphids can be a serious problem if the Reed Beds are being overpopulated by this opportunistic insect. They can be successfully controlled, however, in an environmentally friendly way using Lady Bugs which can be purchased from many organic farming organizations. They should be applied at the rate of 1 gallon per 10,000 sq. ft. It is important to remember that **the presence of aphids is usually a symptom of some other type of Reed Bed stress, which should be investigated and corrected.** Controlling the aphids may not correct the real problem. Check for sludge overloading or volatile solids concentrations in excess of 70%, and call New England Waste Systems, Inc. (NEWS). Success of the Reed Bed System requires more attention during the first year of operation. Once the plants are established the system typically requires less monitoring and maintenance.

Loading Volume Calculations

For large Reed beds where it is difficult to control the 3-4” application rate it is prudent to calculate application volumes by mounting a calibrated ruler on the inside of the digestion tank. The number of gallons being applied is determined by knowing how many digester gallons are leaving for each inch of drop in the digester. The number of gallons needed to provide 4” of sludge in the Reed Bed can be calculated using the following formula:

Application volume = Reed Bed Area in feet (L x W) x .33 feet (4”) x 7.48 gal/ft^3

Remedial Actions in Addition to Aphid Control

Aphid Control: Sludges high in ammonia can stress the Phragmites to the point that the leaves start to turn yellow. The yellowing is generally accompanied by an aphid infestation.

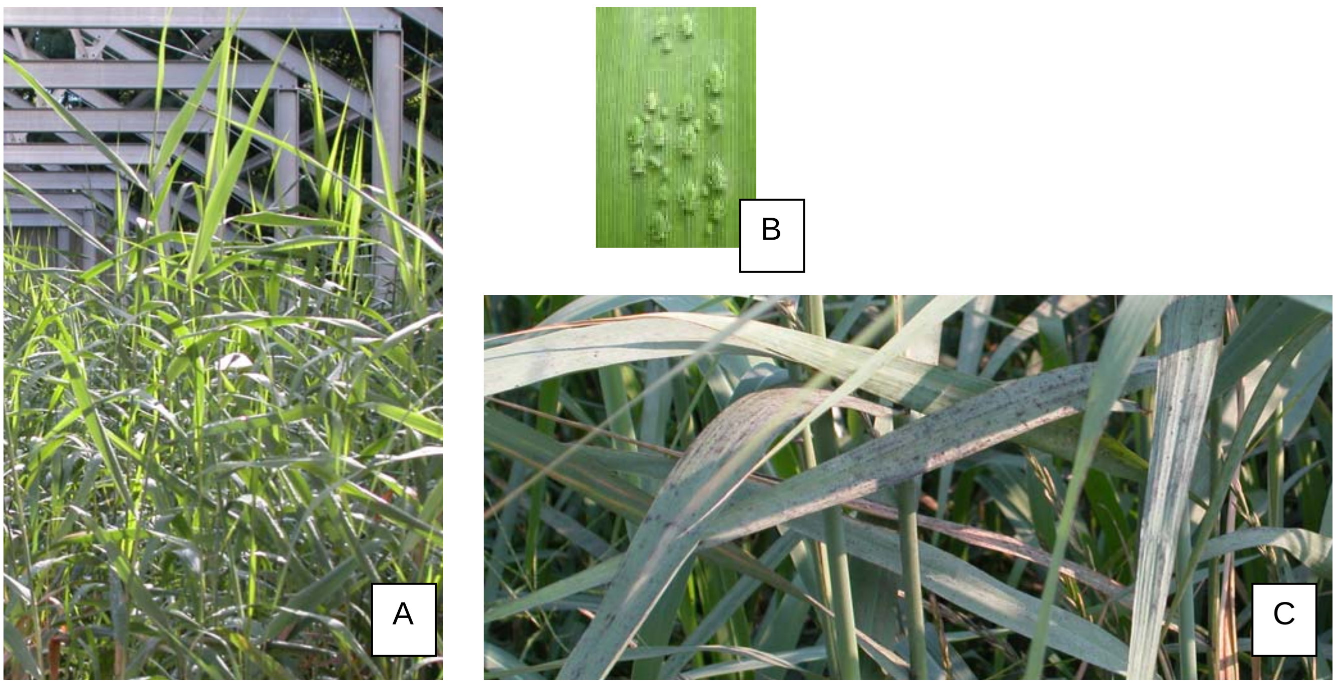


Figure 4. Yellowing of Phragmites plants (A) is indicative of plant stress. Evidence of Aphid infestation (B) remains after aphids have gone (C).

Solution: Immediately begin watering the Reed Bed with plant effluent so that the ammonia can be washed or leached out as quickly as possible. Typically the leaching process will reverse the yellowing trend in about a week. That is also about the same time required for ladybugs to eat the aphids.

Remember Yellowing leaves and aphid infestations are clear signs of stress for Phragmites Reed beds. This is typically due to overloading (i.e. more than 4” every two weeks) or ammonia toxicity. When problems occur it is your “clue” to find out what needs to be done to correct the problem.

Examples:

1. Reduce the loading volume to perhaps 2" per application.
2. Reduce the number of applications (e.g. apply sludge only once a month fro a period of time).
3. Digest the sludge more completely to reduce ammonia concentrations.
4. Analyze the sludge more carefully for % volatile solids and ammonia.
5. Take some digital color pictures and send to NEWS immediately. Call us at the same time.

Appendix A.

History of the Reed Bed System

This Reed Bed technology was developed by Dr. Kathe Seidel at the Max Planck Institute in Germany. Dr. Seidel's experimental work on the action of aquatic plants on polluted waters began over forty years ago and continued for over twenty years. Dr. Seidel was not only the pioneer of the Reed Bed technology but all other systems which use wetland vegetation. She began publishing her results as early as 1957.

The specific application of Phragmites reeds for dewatering sludge was in Ustersbach, Germany, at the Kasirue Nuclear Facility. This project, begun in 1974, is still in operation, dewatering inorganic hydroxide sludge. Another project, for the dewatering of river dredgings was funded and sponsored by the Army Corps of Engineers in 1976.

There are currently over forty Reed Bed Systems in the U.S. treating wastewater sludge as well as one system for the treatment of alum sludge, one for wastewater treatment and one for highway runoff. The Reed Bed System is recognized by the E.P.A. and by several state regulatory agencies as a cost-effective, viable, innovative, and alternative method for handling sludge.

Appendix B

Solids Disposal

Reed Beds vs. The Filter Press

Disposal cost for sludge from wastewater treatment facilities are on the rise. As old landfills close and are replaced by new and more expensive lined systems, tipping fees are rapidly rising. Disposal cost for solids , once a minor part of the wastewater treatment plant's budget, now represents a significant annual expense for many facilities. Any system which will reduce the tonnage of sludge being sent to the landfill, incinerator, or land application site will deliver increasing annual savings.

Compared to a typical filter press, a Reed Bed system will produce 1/6th the tonnage of dewatered sludge for disposal!

Here is how it happens:

Using, as an example*, 500,000 gallons of a typical aerobic sludge at 2% solids, the following tonnages of dewatered material will result from the two systems.

A Filter Press with the ability to produce a dewatered cake of 20% solids concentration will convert the 500,000 gallons of sludge into **208 tons** of material for disposal.

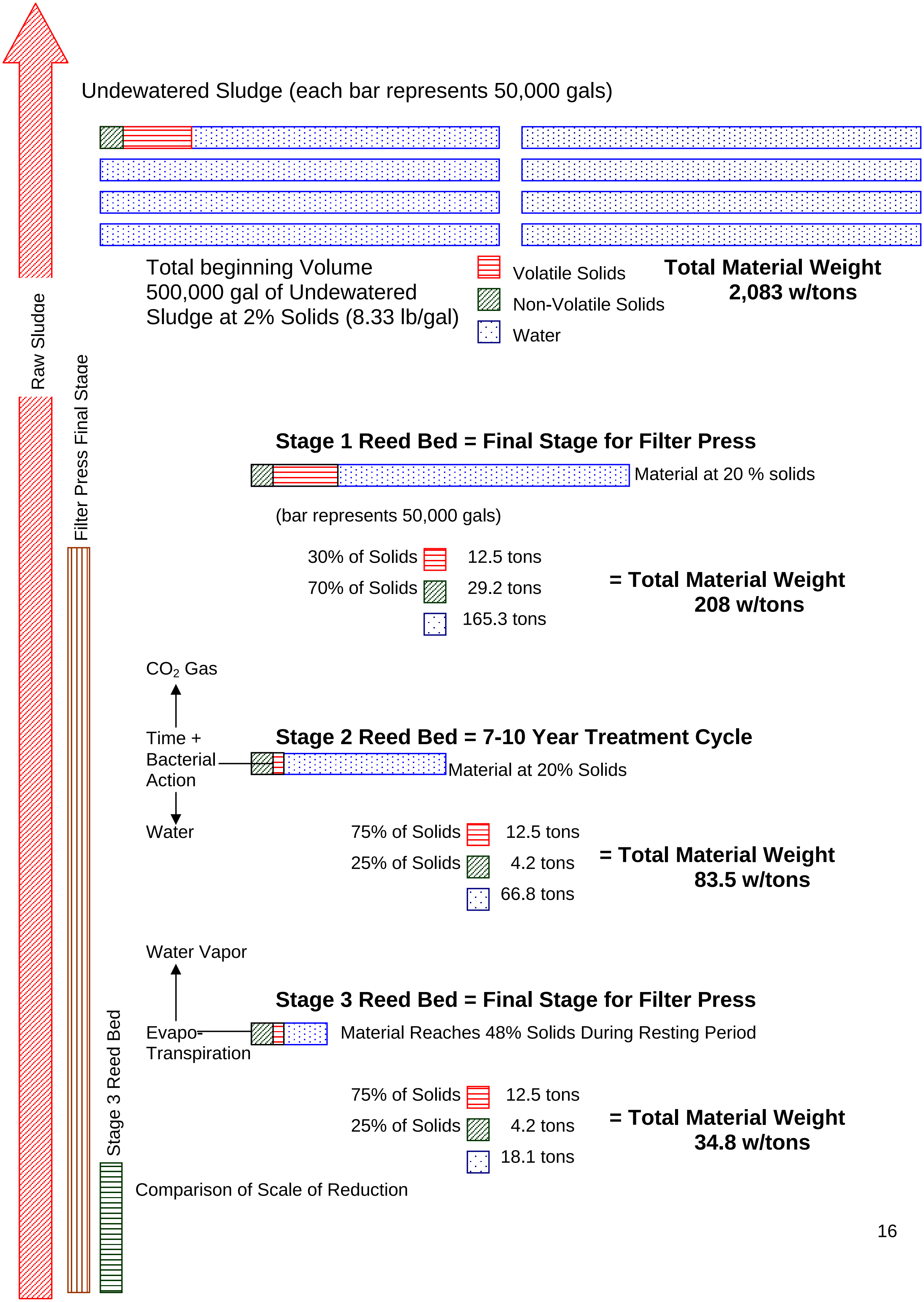
A Reed Bed, however, goes through three separate stages of sludge reduction and treatment.

Stage 1: When applied to its surface, a Reed Bed system will dewater sludge to approximately 20% solids. By weight, the solids in the remaining material are70% volatiles and 30% non-volatiles. The total weight of this material is **208 tons,** exactly the same as what the filter press, shown above, produced.

Stage 2: As the dewatered material in the Reed Bed ages over its seven to ten year treatment cycle, the volatile portion of the solids from Stage 1 are consumed and reduced (converted to CO_2 and water) by a rich bacterial population in the bed. This volatile portion of solids, which began at 70% of the total, is reduced to 25% of the total.

Stage 3: When the Reed Bed is ready for unloading (once every 7 to 10 years) it is taken out of service for 90 days during the summer. This resting period allows the reeds to further dewater, by evapo-transpiration (plants expelling water through their leaves), the material remaining in the bed. This drives the solids concentrations in the remaining material up to 48%, which produces a material similar in consistency to that of moist soil. The final weight of the material left for disposal is **34.8 tons.**

* Example based on actual data from facilities in Marlboro, NJ and Denmark



Raw Sludge
Filter Press Final Stage
Stage 3 Reed Bed
Undewatered Sludge (each bar represents 50,000 gals)
Total beginning Volume
500,000 gal of Undewatered
Sludge at 2% Solids (8.33 lb/gal)
Volatile Solids
Non-Volatile Solids
Water
Total Material Weight
2,083 w/tons
Stage 1 Reed Bed = Final Stage for Filter Press
Material at 20 % solids
(bar represents 50,000 gals)
30% of Solids
12.5 tons
70% of Solids
29.2 tons
165.3 tons
= Total Material Weight
208 w/tons
CO2 Gas
Time +
Bacterial
Action
Water
Stage 2 Reed Bed = 7-10 Year Treatment Cycle
Material at 20% Solids
75% of Solids
12.5 tons
25% of Solids
4.2 tons
66.8 tons
= Total Material Weight
83.5 w/tons
Water Vapor
Stage 3 Reed Bed = Final Stage for Filter Press
Evapo-
Transpiration
Material Reaches 48% Solids During Resting Period
75% of Solids
12.5 tons
25% of Solids
4.2 tons
18.1 tons
= Total Material Weight
34.8 w/tons
Comparison of Scale of Reduction

Apendix C

Reed Bed Photographs

Young Phragmites shoots in spring.

Mature Phragmites plants.

Phragmites plants in early autumn.

Dormant Phragmites plants.

Phragmites plants in winter.