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LEACHATE TREATMENT USING VERTICAL SUBSURFACE FLOW WETLAND SYSTEMS – FINDINGS FROM TWO PILOT STUDIES

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SUMMARY**:** This paper presents pilot study results from two projects in which innovative vertical subsurface flow constructed wetland systems are being used to treat municipal solid waste (MSW) landfill leachate. Horizontal flow wetland systems have been shown to provide poor performance when treating high strength wastewater, especially during winter operation in cold climates. This poor performance is likely due to the onset of limiting anaerobic conditions and the slowing of microbial processes under cold temperatures as winter progresses. In order to overcome these limitations, specialized multi-cell subsurface vertical flow wetland biofilter systems (WBS) have been developed. These WBS are stand alone, fully lined units that are largely pre-fabricated, operate automatically, and require only a small footprint area. The multi-cell setup allows intermittent aerobic-anaerobic zones to be established, which allows aerobic degradation, nitrification, and denitrification of influent to proceed. The pilot study results are promising and indicate that consistently high treatment performance of leachate is possible using the described wetland system. From these pilot study results, it appears that constructed wetlands are a viable option for leachate management, particularly for older landfill units where cost, space, and environmental concerns limit other long-term options.

1. INTRODUCTION

1.1 Leachate treatment using constructed wetlands

The treatment of landfill leachate and other industrial and domestic wastewaters by passage through beds containing common reed plant species (e.g., *Phragmites australis*, *Typha latifolia*) has been widely practiced for many years in a number of countries with varying degrees of success. Although good removal of organic components of effluents and suspended solids is a common finding, poor removal of ammoniacal nitrogen is also typically reported, and this has been considered to limit the value of horizontal flow wetlands for treating raw landfill leachates (Robinson, et al., 1993). This has led to the principal and successful use of constructed wetlands for the treatment of weaker and more dilute leachates from older sites, or for secondary polishing of leachates previously treated by aerobic biological treatment (Barr & Robinson, 1999).

1.2 Subsurface vertical flow wetland biofilter systems

Treatment of leachate using constructed wetlands technology is considered especially applicable to older closed landfill cells with simple soil cover systems, relatively mild leachate, and low landfill gas production rates. Horizontal flow wetland systems tend to provide poor performance when treating high strength wastewater, especially during winter operation. This poor performance is likely due to the onset of severe anaerobic conditions as winter progresses (Rozema, 2000). In order to overcome this limitation, specialized multi-cell subsurface vertical flow wetland biofilter systems (WBS) have been developed and were investigated as part of the pilot studies discussed in this paper. These WBS are stand-alone, fully lined units that are largely pre-fabricated, operate automatically, require only a small footprint area, and, in a project funded by the USEPA and the Ontario Ministry of the Environment, have been shown to effectively treat wastewater in cold climates (Lemon, et al., 1996). From this original research work, the WBS has been successfully commercialized and has been installed at more than 30 project sites since 1998 for treatment of domestic, industrial, and agricultural wastewaters with influent flow rates ranging from 40 to 400 m^3/day.

Proven advantages of vertical flow technology are its ability to maintain high dissolved oxygen concentrations in treated liquid as it travels through the system. This results in very high reductions of BOD and significant nitrification. The WBS also has demonstrated ability to handle high ammonia loading (it has been shown to be capable of providing greater than 90 percent nitrification of ammonia, even when influent ammonia levels exceed 1100 mg/L) and is tolerant of heavy metals (Rozema, 2000). In addition, the systems are capable of treating heavy metals as well as recalcitrant organic pesticides. The WBS may, however, be limited in its ability to provide sufficient denitrification due to limited anaerobic zones and insufficient carbon supply towards the end of the system. Denitrification can be aided by increasing water levels in cells which are expected to provide denitrification in order to provide sufficient anaerobic zones. In addition, organic matter can be used to augment cells to ensure that lack of a carbon source does not become a limiting factor to denitrification.

The overall goal of the pilot studies at the two project sites described in this paper is to demonstrate that use of the WBS technology will eliminate the current high cost of off-site leachate disposal at both sites (leachate is currently transported via tanker trucks to local wastewater treatment plants). In this way, this approach will show that use of the WBS provides an effective, low-maintenance, and cost-effective method for management of leachate, especially at landfill sites where current leachate disposal costs are high and space limitations and environmental concerns limit other long-term options for management and discharge of leachate.

2. PROJECT BACKGROUND

2.1 Description of pilot study sites

2.1.1 Site A

Site A is a closed, 11-ha. landfill cell at an active, publicly-owned facility in the mid-Atlantic region of the U.S. This region receives approximately 100 cm of rain per year with summer high temperatures typically around 30°C with high humidity and winter lows typically just below freezing (although relatively uncommon, snow accumulation over days or even weeks does occur). The cell has a geomembrane liner, leachate collection system, and soil cover, and currently produces approximately 30,000 liters per day of leachate. The site accepted MSW from 1980 to 1988 and contains approximately 740,000 Mg of waste. Landfill operations combined the two lined units into a single disposal area designated Area A/B, and continued until October 1988, by which time approximately 635,000 tonnes of waste had been disposed in the combined 11 ha unit. Area A/B was then capped with a 60 cm thick sandy soil cover in accordance with the regulations applicable at that time. A landfill gas (LFG) collection system was installed, which currently consists of 17 vertical wells and a nearby candlestick flare. Approximately 4,000 m^3/day of LFG are currently collected from Area A/B. The cover is fully grassed and no signs of vegetative stress due to LFG impacts are evident.

Since closure in 1988, Area A/B has generated an average of about 35 m^3/day of leachate. No plans to reduce this quantity by installing a less permeable cap are currently being considered by the owner. Leachate management systems were modified over the years, changing from an open top lined lagoon, to an underground storage tank, to the current system of an underground pump station and above ground storage tanks. Leachate recirculation and spray irrigation were used as the primary means of leachate management for some time, a practice that, in conjunction with the permeable soil cover, has contributed significantly to the relatively mild leachate presently generated at the unit (Morris, et al., 2003). It was eventually necessary to ship leachate to an off-site wastewater treatment plant in addition to recirculation in the waste mass. However, leachate recirculation ceased in March 1995 as a result of regulatory restrictions.

The overall goal of the project is to create a self-sustaining closed landfill unit through the treatment of all leachate generated by the unit in wetlands located on the landfill cell. Currently, installation of a phyto-cap on the landfill unit is proposed to take up all the treated effluent, resulting in no discharge to the environment.

2.1.2 Site B

Site B is an active, privately-owned landfill in the southeastern U.S. The area receives significant amounts of rainfall (approximately 180 cm) throughout the year, with very hot and humid conditions during the summer, and relatively mild winters. The landfill has a composite bottom liner system consisting of a 60 cm thick compacted clay liner with a hydraulic permeability of 10^{-7} cm/sec overlain by a geomembrane liner and a 60 cm sand filter/buffer layer. The landfill has operated since October 1993 and accepts non-hazardous, non-infectious wastes including household garbage, approved special wastes, construction and demolition debris, tires, appliances, yard wastes, dried sludges, paper, and similar materials. Leachate is collected in a network of perforated HDPE pipes installed on top of the composite liner from approximately 26-ha. of active cells. The site has been in operation since 1993 and receives approximately 473,000 Mg of waste per year.

Currently, collected leachate is stored in two large above-ground storage tanks and managed through (i) recirculation for about half of the total flow; and (ii) trucking to an off site publicly-owned treatment works (POTW) for the remaining flow. There is currently no reliable estimate of leachate generation rates due to the management mix of recirculation and offsite disposal, which tends to underestimate real flow rates. Based on initial estimates, the flow rate appears to be on the order of 22,700 liters per day; however, it is suspected that the real flow rate may be as high as two to three times the current estimate. During the pilot phase of this project, the facility will monitor flow rates more accurately.

2.2 Scope and objectives of the WBS pilot studies

The design objectives vary somewhat between Site A and Site B due to the proposed use of the treated effluent from the wetland. At Site A, the treated effluent will be reused to irrigate a landfill phyto-cap that will comprise native tree and grass species. The irrigation system is designed to allow a perennial zero water balance to be established at the site. As a result, the effluent standards developed for the site focus on constituents that may be detrimental to plant growth or that may build up in cover soils over time, potentially stunting plant growth or eventually ending up in surface water runoff. Treated effluent at Site B will be discharged into a stormwater pond with subsequent direct discharge to an adjacent receiving stream/natural wetland area. Surface water quality standards will have to be met at the point of discharge from the stormwater pond.

The preliminary scope of work for both sites required a treatability demonstration of the wetland treatment process at pilot scale (approximately $^1/_{10}$-scale) prior to implementation of the WBS technology at full scale. Operation of the pilot studies also served to allow fine-tuning of the dosing systems so as to most effectively treat leachate from the landfill cells.

2.2.1 Site A

Three $^1/_{10}$-scale pilot study programs were constructed, with each being capable of treating 3,800 liters of leachate per day. The pilot-scale WBS units were constructed and commissioned under closely-controlled conditions during summer so that quick plant establishment under warm weather conditions would allow for more rapid acclimatization of the biological treatment processes. To allow proper comparison between each program (with respect to land area requirements, construction costs, etc.), each system was designed to have approximately the same leachate treatment (contact) area and quantity and type of construction materials.

- Program 1 comprised a standard three-cell WBS. Each cell measured 3.5 m by 3.5 m by 1.3-m deep. The cells were filled with various layers of gravel and coarse sand and planted with cattail plants and common reeds.
- Program 2 comprised a single horizontal subsurface flow cell measuring 6 m long by 3-m wide by 1.3-m deep. The cell was filled with coarse sand and again planted with cattails and common reeds.
- Program 3 combined both technologies and consisted of the Program 2 horizontal cell followed by a single WBS cell measuring 4.5m by 4.5m by 1.3-m deep which was filled with various layers of gravel and coarse sand and planted with cattails and common reeds.

The construction area was a nominally flat gravel-lined vehicle parking area directly adjacent to the landfill cell's master leachate sump. On-site borrow soil (sandy silt) was used to prepare a level base pad as a foundation for the three pilot systems. All WBS cells were double-lined using a synthetic geomembrane material. The secondary containment (leak detection) liner was placed directly on top of the base pad, underneath the wetland cells, which were constructed above grade and directly adjacent to each other. All cell formwork was constructed using wood frame and brace sections and internally lined with plywood sheeting. The primary containment liner was placed inside each cell, draped over the frame of each cell, and nailed in place (above the liquid containment level). A perforated 15 cm diameter "Big-O" pipe was placed around the perimeter of the cells to collect any liquid between the two liners. This pipe was connected to a plastic 200-liter sump barrel fitted with a lid and housing a manually operated submersible pump. Figure 1 presents a plan layout of the entire pilot study program, while Figure 2 presents a cross sectional view of a WBS vertical flow cell.

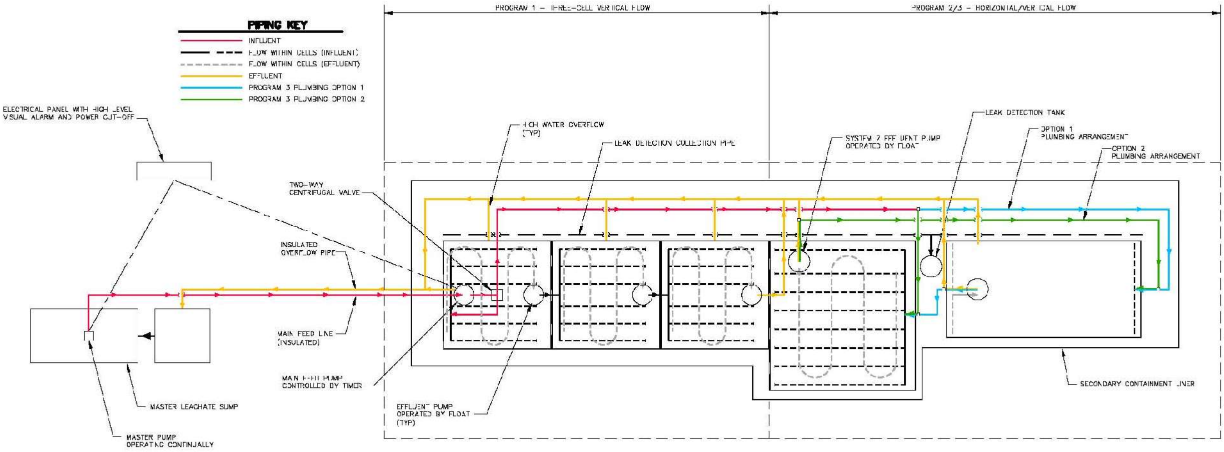


Figure 1: Plan view of site a pilot study program

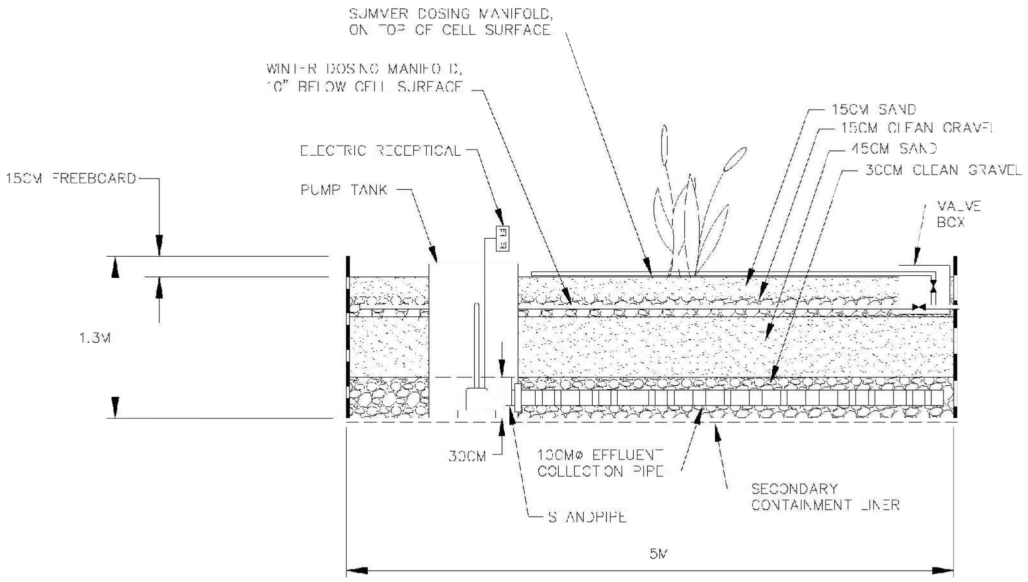


Figure 2: Cross section through typical vertical flow WBS cell

Each WBS cell has a separate summer and winter dosing manifold. The buried winter manifolds are located above the sand media in a 15 cm deep layer of clean coarse gravel. These consist of 7.5 cm diameter solid PVC pipe running across the width of the cell connected to six equally spaced 2.5 cm diameter perforated PVC pipes that run along the length of the cell. Each 2.5 cm diameter pipe is covered with a 7.5 cm diameter perforated PVC pipe cover to help prevent clogging. It has a vertically mounted cleanout connected to it, which protrudes through the top layer of sand in the cell. An additional 15 cm thick layer of clean coarse sand is located above the gravel. The surface of the cell is the top of the uppermost sand layer. The summer manifolds are located directly at the surface, and are identical to the winter manifolds with the exception that they do not require protective pipe covers. Leachate is collected in the bottom of each cell by a 15-cm diameter “Big-O” pipe placed in a serpentine pattern along the bottom of the cell. One end of the pipe is connected to a pump barrel where leachate is stored before being pumped into the next cell. A submersible pump located in each pump barrel is operated by means of a float system. Figure 3 shows the pilot study program soon after completion and after operating for eight months, with the summer manifolds clearly in view. The three-cell WBS is in the foreground, while the horizontal cell is farthest from view.

Figure 3: View of pilot WBS cells at Site A at completion (left) and after eight months of operation (insert right)

Cattail plants (*Typha sp.*) and common reeds (*Phragmites sp.*) were installed in each cell at a ratio of approximately three cattails to every one common reed. These species were selected because they are perennial, semi-aquatic, have demonstrated good performance in constructed wetlands, and are native to Delaware and already present at the site. The plants were installed on 60 cm centers over the surface of the cells in accordance with accepted industry practice in Canada and the U.S.

2.2.2 Site B

A four-cell pilot-scale system was constructed in January 2005. Each treatment cell measures 3 m by 3 m by 1.2-m deep. Due to the warm climate in southern Alabama, the system has not been modified for winter operations (i.e., no insulating soil berms around the treatment cells, and no winter manifold for leachate dosage). Similar to other vertical-flow wetland systems, the cells are filled with a 30 cm layer of gravel and 75 cm of concrete sand, with about 15 cm of freeboard. Corrugated drainage pipe is used within the gravel layer to collect infiltrating leachate. The cells are planted with native wetland reeds and grasses (e.g., phragmites, bulrushes, etc.) collected from onsite sources. The first two cells are operated aerobically with leachate being applied onto the surface of the treatment cells, which allows vertical infiltration through the sand matrix. Leachate is collected in the bottom 30 cm of each cell and pumped to the next cell. Aerobic treatment in these cells allows for nitrification of ammonia and substantial reductions of BOD and iron. The third treatment cell is operated anaerobically to maximize denitrification of previously nitrified ammonia. In order to drive the cell anaerobic, the flow is reversed, with the cell being filled from the bottom up. A gravel layer with corrugated pipe near the surface of the cell collects the leachate and conveys it to a pump barrel for transfer to the last treatment cell. In addition, a carbon source (i.e., aspen mulch) for the denitrifying bacteria is provided in the third cell. High water levels and added organic carbon in this cell result in anaerobic conditions. The fourth cell is operated aerobically again, and includes a recirculation mechanism for added retention time to polish the leachate (i.e., to treat BOD that may have been picked up in cell 3). Currently, the system is pulse-dosed at approximately 1900 liters per day.

The pilot system was constructed next to two large leachate holding (equalization) tanks at the site. Leachate dosed into the wetland system is taken from the bottom of one of the large tanks. Initial observations have revealed that this practice delivers influent leachate that is “fairly sludgy” which means the sand matrix on top of the first WBS cell regularly clogs. Clogging is compounded by deposition of a thin surface layer of precipitated iron and manganese. This, in turn, leads to water ponding, which inhibits oxygen diffusion into the subsurface and, therefore, aerobic treatment of the leachate. To address this, the pilot system will be amended with a pretreatment cell (containing no sand) to serve as a holding/settling pond (this cell was being installed at the time of writing). Once operational, clear influent leachate will be drawn from the top of this cell. This pretreatment step may also result in a reduction of influent ammonia concentrations (currently on the order of 400 mg/L to 500 mg/L), improving the overall treatment efficiency.

3. RESULTS

3.1 Site A

The pilot study for Site A was operated for 10 months commencing in September 2003. Results from the completed pilot study at Site A have demonstrated very successful removal of BOD (average influent = 30 mg/L, average effluent = 3.6 mg/L) and ammonia-nitrogen (average influent = 211 mg/L, average effluent = 3.4 mg/L) after acclimatization, as well as almost complete removal of iron (average influent = 35 mg/L, average effluent = 0.16 mg/L) and phosphorous (average influent = 0.4 mg/L, average effluent = non-detect), and good removal of TSS (average influent = 89 mg/L, average effluent = 13 mg/L).

In order to assess the performance of the treatment processes, samples of leachate influent and effluent were collected twice a month and analyzed for a suite of biochemical, chemical, and physical indicator parameters, including BOD, COD, TOC, ammonia, nitrate, nitrite, TKN, phosphate, TSS, TDS, pH, iron, magnesium, chloride, total alkalinity, and 12 heavy metals. For the purposes of this paper, the results for several important indicator parameters are presented in Figures 4 through 7 below. These parameters are BOD, ammonia, nitrate, and iron.

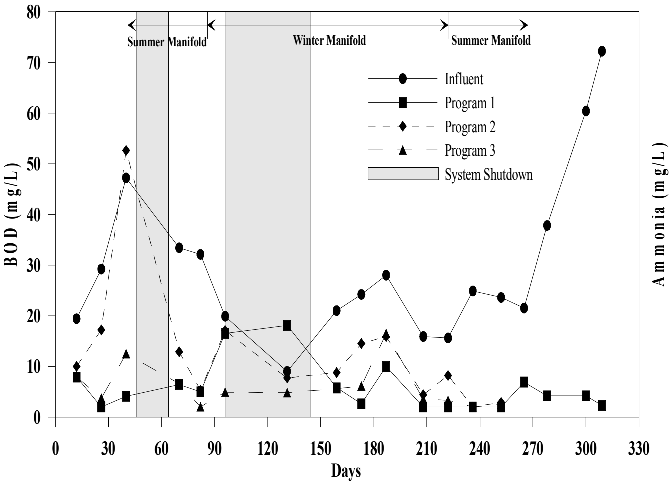


Figure 4: BOD concentrations at Site A

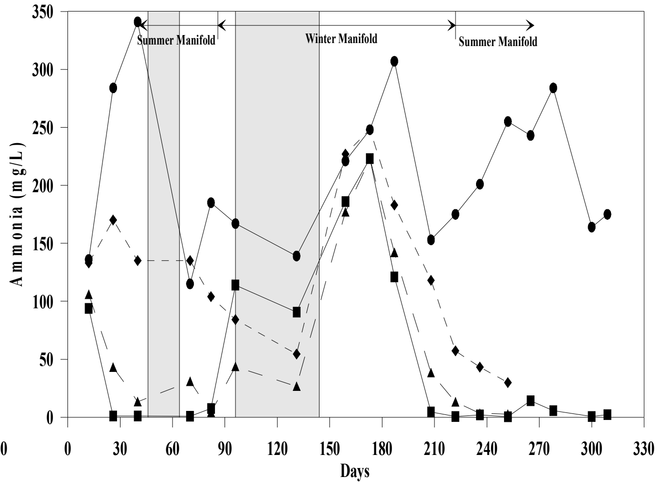


Figure 5: Ammonia concentrations at Site A

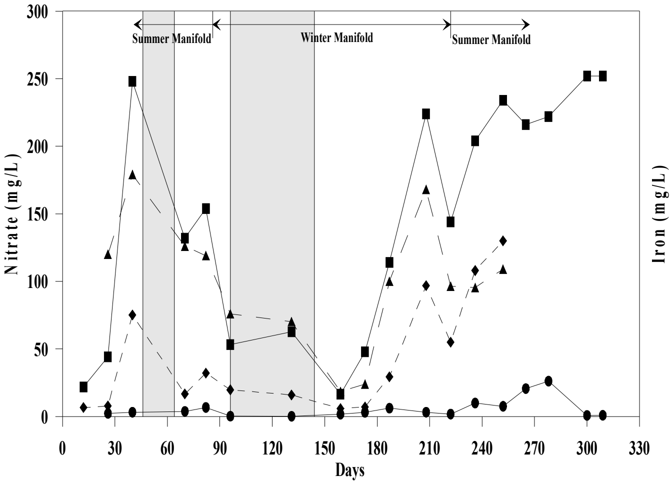


Figure 6: Nitrate concentrations at Site A

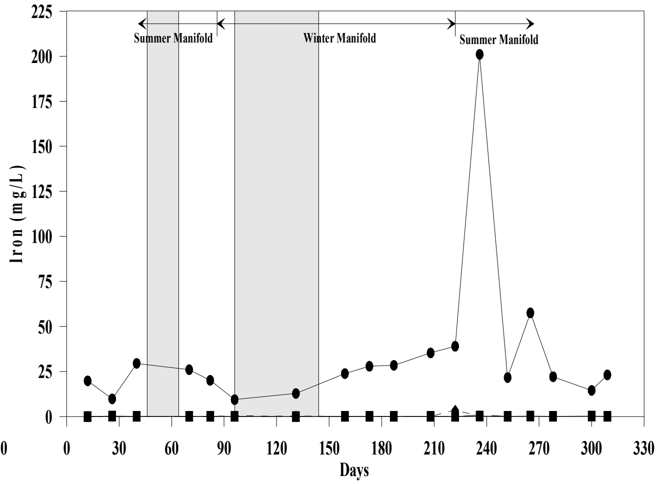
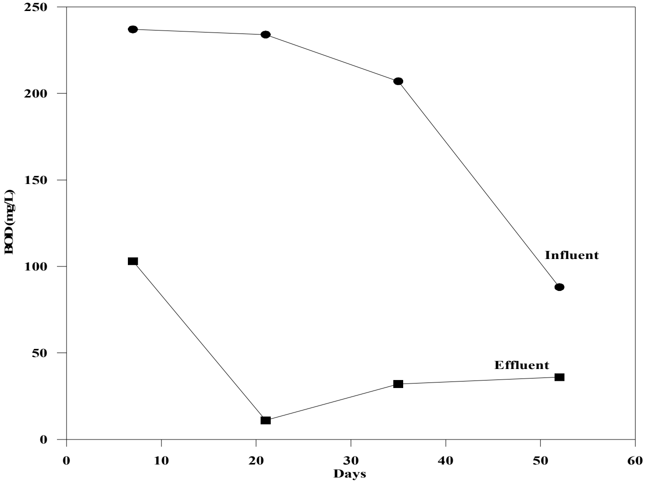


Figure 7: Iron concentrations at Site A

The pilot study operated for a total of nine months. However, due to operational issues involving the pumps, the system was operated somewhat intermittently for the first five months after startup. Periods of major shutdowns and system inactivity are indicated on the data plots. Once the system was restarted, 140 days into the program, problems were minimal and the system essentially ran continually.

3.2 Site B

Operation of the pilot study at Site B commenced in January 2005. The pilot project will run for one year with two sampling events per month for a total of 24 sampling events. The first four sampling events had been performed at the time of writing (i.e., only preliminary results are included in this paper; further data will be available for presentation at the symposium). Some initial data for BOD and iron are presented in Figures 8 and 9, respectively.



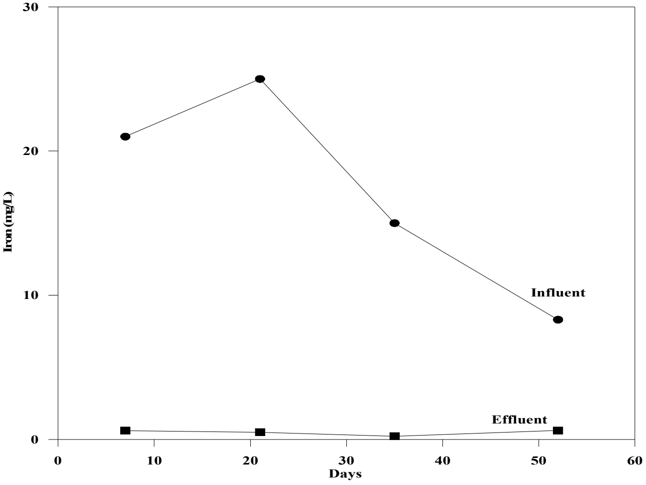


Figure 8: BOD concentrations at Site B

Figure 9: Iron concentrations at Site B

Other preliminary results for Site B look promising, but it is still too early to draw any definitive conclusions as the program is still in the start-up phase.

4. DISCUSSION

The results for Site A show excellent biological treatment of BOD and nitrification of ammonia in all three programs, although Program 1 (three-cell vertical flow WBS) has generally delivered results with better consistency and, as expected, ammonia treatment achieved in Program 2 (horizontal flow wetland cell) has been significantly worse than in the other programs. The performance of all three programs were impacted significantly by the long period of inactivity 100 to 140 days into the program, although it is not possible to ascertain whether using the winter dosing manifold (when oxygen availability will be more limited) contributed to this. Very little denitrification of nitrate is apparent in Program 1, probably due to the third WBS cell having an insufficiently deep anaerobic zone. Denitrification in Programs 2 and 3 (primarily brought about by the horizontal cell) is also sluggish, probably indicating that the system may be carbon-limited. Removal of iron has essentially been total, mainly as a result of filtration and precipitation of iron (oxy-) hydroxides. The top one or two centimeters of soil in cell 1 of Program 1 bears considerable iron staining, and may need replacing if clogging becomes an issue. Removal of other metals (e.g., magnesium, not shown) and TDS has not been observed to any significant degree.

The initial data from Site B show efficient treatment of BOD, COD, and all VOCs detected in leachate, as well as efficient removal of iron. Nitrification of ammonia is not yet well established, although the treatment efficiency appears to be increasing as the system matures. It is suspected that the previously described problem with clogging and ponding in the first aerobic treatment cell may have negatively affected the nitrification process. The modified system including a pretreatment cell is expected to substantially improve ammonia treatment. Notwithstanding these initial minor setbacks, it is encouraging that a persistent slight decrease in ammonia and TKN concentrations in effluent has been observed without a concurrent increase in nitrate concentrations, indicating that denitrification is occurring in cell 3. The removal of nitrogen is one of the most important treatment steps prior to discharge of treated leachate to receiving surface waters. Furthermore, the complete treatment of VOCs, BOD, and iron supports the viability of this treatment technology.

5. SUMMARY AND CONCLUSIONS

The pilot study results indicate that consistently high treatment performance of leachate is possible using the described WBS. Although the study at Site B is in initial start-up phase and it is therefore too early for any final conclusions to be drawn, it appears that vertical subsurface flow WBS units can be effective at providing biodegradation of organics as well as nitrification and denitrification of ammonia-nitrogen. The latter biological treatment processes will likely prove to be critical if effluent quality is limited by nitrate concentration (which is typically the case for surface water discharge). From these pilot study results, it appears that constructed wetlands are a viable option for leachate management, particularly for older landfill units where leachate disposal costs, space, and environmental concerns limit other long-term options.

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