DESIGN AND OPERATIONS REPORT FOR
THE OPTIMIZATION OF THE GREEN LANE
LANDFILL SITE

ST. THOMAS SANITARY COLLECTION SERVICE LIMITED
APPENDIX M

LITERATURE REVIEW AND APPLICATION
- LANDFILL BIOREACTOR TECHNOLOGY
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1.0 INTRODUCTION

1.1 PREAMBLE

Terms of Reference (ToR) for an environmental assessment (EA) for the proposed Optimization of the Green Lane Landfill Site (Site) were approved by the Minister of the Environment on March 28, 2002. In support of the associated Environmental Assessment (EA) Act and Environmental Protection (EP) Act applications, a number of studies are to be completed, some of which are dependent on projected waste volumes and tonnages. To that end, CRA prepared a memorandum entitled "Estimated Waste Volumes and Tonnage for the Optimization of Green Lane Landfill" dated July 9, 2002 (CRA July 9, 2002 Memorandum).

From a technical perspective, the elements of Landfill Bioreactor Technology (LBT) reviewed below are not dependent on waste volume and tonnages. Therefore, the discussions below regarding applicability of LBT at the Site apply equally to all of the airspace optimization options reviewed in the CRA July 9, 2002 Memorandum, including full optimization (expansion to the east and west and increases in height and depth). However, this report does not address any operational considerations that the Site Proponent may have regarding the desirability of implementing LBT elements under the various optimization options.

1.2 PURPOSE

Bioreactor landfills, or as they are sometimes called, energy cells or rapid stabilization landfills, represent an important advancement to landfill engineering. A number of very significant opportunities may be available through the adoption of the fundamental principles of LBT. These advances are applicable to current operating landfills such as Green Lane Landfill, as will be demonstrated in the following sections. It is noted that key elements of the LBT are currently approved for use at the Site, including leachate recirculation and landfill gas (LFG) recovery and utilization.

This report focuses specifically on components of LBT that can be applicable to operating landfills in general, and Green Lane Landfill, specifically. This report is presented in several sections which refer to specific elements which impact the performance of LBT including: leachate recirculation; organic content; leachate quality and quantity; leachate volume and storage; alternative daily cover; LFG generation; landfill temperature; and contaminating lifespan. It concludes with the comparative
advantages and disadvantages of applying this technology at the Site and suggests alternative levels of effort for LBT implementation at the Site.
2.0 BACKGROUND

Anaerobic conditions naturally dominate in sanitary landfills, generating methane and carbon dioxide, which are the primary end products of anaerobic decomposition. Conventional sanitary landfills are generally referred to as "dry tombs" because the approach taken in designing them is to minimize water from contacting the waste with a view to minimizing excursions of the resulting leachate into the groundwater. This practice also limits the rate of anaerobic activity within the waste.

The term "bioreactor" refers to a sanitary landfill that is engineered to optimize the microbiological processes that transform readily decomposable organic waste constituents and accelerate the gas production and leachate chemistry to stabilize these components in a comparatively short timeframe. Dependent on landfill construction and post-closure intended use, applied LBT may involve anaerobic, aerobic, facultative, or a combination of anaerobic-aerobic processes.

Landfill bioreactors are, in essence, a treatment system for waste (Reinhart and Townsend, 1998). The time needed to degrade organic waste constituents in a landfill bioreactor is reduced significantly. Initial short-term studies show a reduction in chemical oxygen demand (COD) half-life from a decade to less than a year (Reinhart, 1995). Thus, the potential exists to reclaim stabilized landfilled material and increase settlement rates, thereby extending the operating life of a landfill. LBT operations are most efficient and effective where the refuse has a high organic content and a large exposed surface area but the principles apply regardless of the waste type and composition.
3.0 LEACHATE RECIRCULATION (MOISTURE ADDITION)

Moisture is the primary limiting factor in waste degradation (McBean et al., 1995; Reinhart, 1995) and, therefore, adequate moisture is an essential requirement in a functional bioreactor. The maximum moisture content of the waste, prior to the production of leachate, is referred to as "field capacity". The addition of moisture to attain and exceed field capacity conditions in the waste results in enhanced biodegradation rates. The specific moisture content of the waste at field capacity varies with the waste composition, density, and porosity, and is difficult to determine because of the heterogeneous nature of the waste and channeling of leachate through paths of low hydraulic resistance. Studies have determined field capacity moisture content to range between 29 percent and 44 percent of the waste volume (v/v) (Yuen et al., 2001) although first appearance of leachate from waste occurs at much lower moisture contents due to leachate channeling.

Leachate recirculation has been identified as a useful means to promote moisture conditioning of the waste. In some instances, surface infiltration processes and the production of leachate within the refuse itself may not be sufficient to attain field capacity. Therefore, alternative sources, such as purge well water, stormwater, sewage sludge, and any other non-hazardous liquid wastes, may be used to augment available leachate for recirculation.

Leachate recirculation can create an enhanced environment, favorable to rapid microbial decomposition of biodegradable solid waste, compared to the "dry tomb" concept. Leachate recirculation can provide a means for the distribution of nutrients and enzymes, a medium for pH buffering, dilution of inhibitory compounds, recycling and distribution of methanogens, and liquid storage. The effectiveness of leachate recirculation has been well documented; however, the full-scale leachate recirculation methodologies and operations are still evolving, and limited design and operating data are available.

The following illustrates some case studies across North America and Europe that implemented leachate recirculation programs. Most of the projects focus on managing and reducing the quality and quantity of leachate that must be sent for treatment and disposal, in order to reduce overall disposal costs. Very few, if any, of the projects implemented leachate recirculation for the specific purpose of enhancing the rapid stabilization of the wastes. There is limited published data available on field results focusing on landfill settlement, gas generation, and hydraulic conductivity.
Mountain View, California

According to Pohland and Harper (1985), a demonstration project for leachate recirculation was undertaken at the above site. The demonstration landfill site was divided into six cells, each containing 5,200 tonnes of refuse with an average volume of 10,500 m$^3$ each. The cells were treated differently with regard to moisture addition and control, pH adjustment, sludge seeding, and nutrient addition. Although the recirculation program was somewhat erratic, leachate recirculation and pH control resulted in higher LFG production rates than in control cells. Routine leachate analyses were not performed in this study making it difficult to present any definitive conclusion about improvement in leachate quality that may have resulted from the leachate recirculation.

Seamer Carr, North Yorkshire

Barber and Maris (1984) conducted a full-scale investigation of recirculation of leachate at a lined landfill in Seamer Carr, North Yorkshire. In part, they concluded the largest source of leachate discharge reduction could be attributed to the development of a perched water table on the intermediate cover within the landfill. They suggested that prior to the implementation of recirculation at a landfill, due consideration should be given to the potential for the development of perched water tables within the waste. Areas above intermediate low permeability cover areas, were noted as the likely location for perched areas of saturation. Similar problems with the horizontal movement and leachate ponding within the waste mass were reported at the Lycoming Country Landfill, PA, where clays and silty soils were used for daily cover (Warith and Sharma, 1998).

During the first 20 months of the study in Seamer Carr, a 40 percent decrease in leachate COD was observed compared to the COD levels of leachate from a control area. A 'marked' decrease in TOC concentration was also noted in the leachate from the recirculation area. The pH values were observed to increase with decreasing strength of the leachate (Barber and Maris, 1984).

Trail Road Landfill, Nepean, Ontario

Leachate recirculation was studied at Stage 3 of the Trail Road Landfill in Nepean Ontario between 1992 and 2000 by Warith et al. (2001). The site has a composite clay and geomembrane liner and received on average 225,000 tons of solid waste annually during the study period. Infiltration lagoons located on top of the waste were used to
provide moisture and the location of these lagoons was changed on a regular basis to provide some distribution of the leachate into the landfilled refuse.

Several leachate parameters were monitored during the study, including pH, biological oxygen demand (BOD), and COD. The pH was initially below neutral at the start of leachate recirculation and after 3 years it was observed to be nearly continuously above neutral. Over the entire study period a decrease was noted in concentration of BOD and COD in the leachate. The ratio of BOD/COD decreased from 0.9 in 1992 to 0.3 in 2000. A ratio value of 0.4 was achieved approximately 5.5 years into the study. Other observations noted during the study included:

- increases in odour emissions, which necessitated the installation of an active gas-recovery system in 1998, 6 years into the study;
- a recovery of approximately 30 percent of the landfilling space due to enhanced settlement of the waste as a result of leachate recirculation;
- short-circuiting, caused by the heterogeneity of the waste, prevented the waste from reaching 100 percent of its field capacity; and
- prior to reaching field capacity, leachate generation was observed.

It was further suggested that to avoid head on the liner, any rapid stabilization design should include pumping capacity for two to three times the predicted leachate generation rates (Warith et al., 2001).

**Yolo County Landfill, California**

Two hydraulically separated, 30 m by 30 m cells, were constructed to investigate impacts of rapid stabilization. Leachate was introduced through a leach field at the top of one of the 12 m deep cells (second cell serves as a control). Leachate was pumped to a distribution manifold located at the top of the test cell. From the manifold, leachate was then introduced at 25 locations across the surface through leachate injection pipes imbedded in a 1.5 m deep tire chip filled injection pit (Reinhart and Townsend, 1998).

Over an 18-month period during the study, a 30 percent increase in LFG generation was observed in the test cell compared to the control cell. This increase in LFG generation has resulted in the test cell producing a greater percentage of its expected methane yield over time than the control cell, yet an increased methane energy potential has not been noted. The average settlement in the test cell was reported to be 74 cm, which greatly exceeded the 23 cm observed in the control cell. Also, a waste absorptive capacity of
45 gallons of liquid per ton was determined not to cause operational problems (Magnuson, 1998).

**Delaware Solid Waste Authority, Delaware**

Delaware Solid Waste Authority (DSWA) operates three landfills in New Castle, Kent and Sussex counties in Delaware. Rapid stabilization has been performed at these facilities for a number of years. Central Solid Waste Management Center (CSWMC) in Sandtown, Kent County, DE began operations in October 1980 and has five sections designated Areas A through E (Area E contains two 0.4 hectare test cells). All of the cells are lined and equipped with leachate collection and recirculation facilities. Rapid stabilization has been accomplished by various methods including vertical recharge wells, spray irrigation systems, and surface application. Recirculation by recharge wells was found to be simplest and most effective with recharge rates for the wells ranging from 76 to 760 litres per minute (L/min).

A decline in the organic strength of leachate, enhanced by rapid stabilization, was observed after closure in late 1988 for Area B. Areas A, B, and C generated gas early during the operating period and composition was observed to be 55 percent methane and 45 percent carbon dioxide by volume (Reinhart and Townsend, 1998).

**Pecan Row Landfill, Lowndes County, Georgia**

Individual 1.5 to 1.6 hectare cells are constructed approximately every 7 months. The first phase was constructed in 1992 and became operational later the same year. Leachate collections pipes convey leachate to a shallow, double-lined 3,100 m³ lagoon. Rapid stabilization is accomplished by pumping through three 15 cm polyethylene force mains to the fill area. Corrugated, perforated, lateral pipes branch off the forcemains. A separate recirculation system is provided at each waste lift. Leachate is pumped for 1 hour and then discontinued for 1 hour. Using 0.03 cm (12-mil) polyethylene sheeting as temporary cover over areas not receiving waste minimizes leachate generation. Difficulty was encountered in recirculation during early operational phases when insufficient waste was available to absorb the moisture. Also, recirculation near the waste surface or slope led to leachate outbreaks (Reinhart and Townsend, 1998).

The following summarizes specific design and application methods discussed by Reinhart (October 1995a), for various full-scale "bioreactor" operations throughout the United States:
• Southwest Landfill, Alachua County, Florida:
  - A 10.9 hectare composite lined facility that commenced operation in spring 1988 and continues to accept 907 tonnes per month of MSW to a maximum fill height of approximately 20 m;
  - The facility is permitted to recirculate 227 m$^3$ per day of leachate. Leachate drains by gravity through the leachate collection system to a sump and is pumped to four 341 m$^3$ storage tanks. Excess leachate is treated using a high lime precipitation process and transported off site to local water treatment facility (WTF);
  - Between 1990 and 1992, over 30 million litres of leachate were recycled to the landfill through the use of infiltration ponds;
  - Direct injection of leachate into landfill lifts, commenced in 1993, by means of horizontal pipes placed in 2.4 m wide and 122 to 213 m long trenches filled with tire chips. The first trench is 6 m above the liner, with subsequent trenches at intervals of 6 m (vertical) and 15 m (horizontal). To allow for the selection of leachate introduction location within the landfill area, each lateral is valved separately. The first two laterals received approximately 7.6 million litres over a 6-week period; and
  - To allow extraction of gas during the active landfill phase, recirculation laterals were connected to the LFG recovery system in 1994.

• Central Facility Landfill, Worcester County, Maryland:
  - The first of four 6.9 hectare cells lined with 0.15 cm HDPE geomembrane on top of natural clay commenced operation in 1990. The facility accepts an average of 181 tonnes per day of waste. The maximum fill height is expected to be approximately 27 m;
  - Leachate is collected through drains consisting of pea gravel and perforated PVC pipes and carried to sumps located at the four corners of the cell. From there it is pumped to a 1,514 m$^3$ storage tank;
  - Vertical discharge wells constructed of 1.2 m diameter perforated concrete manhole sections, recirculate leachate. To prevent leachate short-circuiting, the first section rests on a concrete base and is filled with concrete, while subsequent new sections are added at each waste lift and filled with gravel. A 5 cm PVC standpipe is installed within each well to vent gas and permit monitoring of water depth. A fire hose is transported between the wells to introduce leachate;
  - Excess leachate is transported by truck to a local WTF; and
  - Site observations from this project have indicated a need to modify the design to promote the movement of leachate laterally away from the wells.
Lower Mount Washington Valley Secure Landfill, Conway, New Hampshire:
- Eight 0.3 to 0.4 hectare, hydraulically separated, double-lined cells constructed in January 1992 receive an average of between 9,070 and 13,600 tonnes per year
- Recirculation commenced in the first cell in May 1992, primarily by means of manual pre-wetting of waste using a fire hose. This method improved compaction and wetted the waste efficiently. In addition, a PVC pipe manifold placed in a shallow excavation of the daily cover was also used. Horizontal trenches installed on waste slopes to limit horizontal movement of leachate and improve recirculation in these areas were discontinued due to short-circuiting of leachate resulting from the proximity of the sand drainage layer; and
- This operation found that leachate recirculation does not result in excessive head on the liner, and that LFG measurements suggested stimulation of biodegradation of waste.

Mill Seat Landfill, Monroe County, New York:
- Opened in May 1993, this facility hosts a bioreactor research project consisting of design, construction, and monitoring of leachate recirculation systems. The maximum fill height is expected to be approximately 34 m;
- The site consists of three hydraulically separated, double composite lined cells consisting of one control cell (gas collection only), and two test cells that use different recirculation techniques. The project is designed to determine the effects of recirculation on rate of waste stabilization, quality of leachate produced, and volume of methane emitted;
- The first leachate recirculation system utilizes three pressurized loops within the cell consisting of trenches containing perforated HDPE pipe and filled with permeable material. Leachate collected will be redirected back to the trenches;
- The second system utilizes deep horizontal trenches filled with permeable wastes. To enhance recirculation prefabricated infiltrators will be placed within each trench and chimneys constructed to allow continued feeding of leachate as waste is placed on top; and
- Monitoring of relative moisture content will be carried out and as recovery from both the pressurized loops and chimneys will be performed.

Examples of Other Full-scale Operations:
- Winfield Landfill, Columbia County, Florida: Opened in September 1992, this facility utilizes one leachate sump, an aerated storage lagoon, and distribution by means of portable spray/sprinkler system;
- Coastal Regional Solid Waste Management Authority Landfill, Craven and Carteret Counties, North Carolina: Two facilities commenced operation in 1990.
Leachate drains by gravity to manholes connected to a common sump and is then pumped to lagoons equipped with floating mechanical aerators to provide oxygen for biological treatment of leachate. Recirculation is accomplished by pumping leachate back to first waste lift using a flexible hose and movable vertical injection system;

- Lemons Landfill, Stoddard County, Missouri: Operations at this facility commenced in October 1993. The facility utilizes vertical leachate recirculation wells, irrigation of leachate and storage ponds;
- Gallatin National Bafflefill, Fairview, Illinois: Spray exposed surfaces of waste daily using a water truck. Perforated piping installed at various elevations for distribution and also serve as gas extraction well; and
- Viborg, Denmark: Two test cells containing 450 m$^3$ waste each, constructed to evaluate biogas production. One cell contains household waste, the second both household and yard waste. Leachate recirculation occurs in both cells.

Full-scale leachate introduction/recirculation may be facilitated through various methods, including pre-wetting of waste by means of spraying or using a hose, leachate surface spraying utilizing a portable system, surface infiltration ponds, and/or leachate injection into waste through horizontal or vertical wells and/or pipes.

The climate in southwestern Ontario may limit the number of recirculation methods that are feasible at the Site, due to freezing conditions during one-third of the year. In addition, surface application of leachate often causes concerns about increased odour generation. Subsurface leachate injection remains the most suitable option for recirculation for the Site. In addition to the insulating properties of the interim or final cover, heat generated during anaerobic decomposition should be sufficient to keep recirculation pipes from freezing. However, it is suggested, as a component of implementing the leachate recirculation program and LBT concept at the Site, that consideration be given to testing recirculation in the active area, such as pre-wetting the waste.

Horizontal subsurface distribution systems are being utilized at several full-scale operations, including the leachate recirculation trenches currently approved for the long-term expansion of the Site. Horizontal trenches are excavated into the waste and filled with permeable material to distribute leachate by perforated piping, gravity, or injection. The advantage of this type of system is its usefulness during both the active life of the landfill and during closure (if constructed as part of the cover system). Problems encountered with horizontal wells include the leachate flows from the trenches leading to increased leachate collection rates, adverse affects to trenches as a
result of landfill subsidence, and potential long-term biofouling which may lead to reduction in permeability of trenches. In addition, waste is highly anisotropic in nature, meaning the hydraulic conductivity may be an order of magnitude or two higher in the horizontal direction as compared to the vertical direction (McCreanor and Reinhart, 2000). This can result in a lack of wetting in the lower portions of the landfill and in cases of quick leachate reintroduction, it can result in subsurface artesian conditions and seeps.

The exclusive use of vertical injection wells for leachate recirculation has also resulted in problems, including insufficient wetting in the upper portion of the landfill (McCreanor and Reinhart, 1996). Other concerns with vertical injection wells include damage to the liner if the well rests on the liner or if the exact depth of the liner is unknown at the time of installation. Vertical wells must be constructed to minimize short-circuiting of the leachate back into the leachate collection system at the bottom of a cell. The most effective recirculation system is likely one consisting of both horizontal and vertical injection wells (McCreanor and Reinhart, 1996). Rest periods between pumping generally enhance infiltration rates using this system.

The layout of the injection wells must be carefully considered. Modeling studies performed to simulate the movement of water through waste have concluded that the influence distance of a recirculation well is related to the recirculation rate. Engineering for placement of injection wells must also take into consideration the potential interference with waste placement and compaction, as well as the potential future uses of the Site.

Important generic design criteria to be considered when implementing leachate recirculation, include the following:

- **Leachate Volume**: The ability of the landfill liner to accommodate additional leachate volume generated during leachate recirculation. (i.e., head of leachate on the liner is a function of the drainage length, liner slope, permeability of the drain and liner, rate of moisture impingement, and capacity of ex situ storage and treatment);

- **Waste Compaction**: Over-compaction of waste will impact leachate flow as increased waste density decreases hydraulic conductivity, therefore preventing uniform moisture distribution through the waste (McCreanor and Reinhart, 2000). In some cases, pre-wetting of wastes may be considered to enhance compaction efficiency and promote biological activity;

- **Field Capacity**: Additional moisture sources may be required to bring the waste to field capacity, should the landfill not produce enough leachate to fulfill this demand;
- **Recirculation Devices**: The method by which leachate recirculation will be implemented at a site, must be compatible with daily operation and closure requirements;

- **Leachate Characteristics**: Leachate characteristics will change over time and impact ex situ treatment and disposal methods;

- **Pretreatment**: Pretreatment of waste may be desirable to enhance biological/chemical activity (e.g., shredding or screening of waste);

- **Monitoring**: Monitoring of both leachate and gas quality/quantity is critical to operational decision making; and

- **In situ Monitoring**: In situ systems to monitor moisture, hydrostatic pressure, temperature, and settlement.

Recirculation of leachate is an integral design component of the Long-Term Expansion Area. Design criteria/features currently incorporated for the leachate recirculation program that are also compatible with the concept of the LBT technology for use at the Site include the following:

- horizontal subsurface distribution systems consisting of pump station, forcemain, valve chambers, and leachate recirculation trenches;

- leachate collection system sized to accommodate expected leachate flows from the recirculation activities;

- landfill hydraulic trap design ensures leachate mound concerns are addressed;

- enhanced in situ treatment of the recirculated leachate should improve leachate quality and will reduce the organic loading to the on-Site leachate treatment plant;

- landfilling by stage may allow additional control of compactive effort that is compatible with the leachate recirculation program and hence LBT operations; and

- leachate quality and quantity monitoring will provide information on the performance of the leachate recirculation efforts.

It is noted that there have been operational difficulties with the leachate injection practices encountered with leachate recirculation efforts at other landfills, as illustrated in the above examples identified since the Green Lane 1996 D&O Report was prepared. It is suggested that consideration be given to augmenting the leachate distribution system with vertical injection wells in addition to the approved leachate recirculation trenches at the Site. In addition, some success has been observed with the use of modified LFG extraction wells used to inject leachate that may be considered for the Site.
Additional moisture that may benefit the LBT concept over and above that provided from the leachate recirculation program on Site is currently not available.
4.0 ORGANIC CONTENT

There is a direct correlation between the amount of organic waste in a landfill and the concentration of organic constituents such as COD and BOD. In addition, the amount of LFG produced at a site is proportional to the amount of organic material in the landfill (McBean et al., 1995). The Site presently receives primarily industrial, commercial, and institutional (ICI) waste, with some domestic solid waste, and small quantities of contaminated soils and municipal sewage sludges. Therefore, the waste streams entering the Site contain a somewhat smaller fraction of organic material than those landfills that accept a majority of municipal solid waste (MSW).

Historically, the Site has accepted a higher percentage of ICI waste than that of a "typical" MSW landfill. This tends to reduce the putrescible component of the waste landfilled but the amount of reduction is difficult to quantify. However, it is noted that ICI waste typically can or may contain the same characteristics of MSW waste (i.e., includes organic waste from businesses and multi-unit residential units that generate MSW type waste).

No information could be found on the application LBT to landfills which contain a smaller than average fraction of organic waste. It can be assumed, however, that less organic material in the landfill will result in less concentrated organic constituents in the leachate and reduced overall LFG production. In a well managed bioreactor landfill, the organic constituents of the landfill are effectively treated through recirculation and the LFG generated is collected and can be utilized. Therefore, the addition of organic material to the landfill adds to the production of a potential resource that can then be drawn from the landfill.

Based on the existing and potential contracts to accept MSW from communities currently in the process of closing landfill space, this otherwise conservative estimate for the quantity of MSW accepted at the Site in future years will increase. In particular, Green Lane has the contract from York Region to accept approximately 50,000 tonnes of MSW per year commencing in 2003 and operating for a minimum 5-year term (future 5-year terms available).

Based on the above, the current and future organic fraction of waste at the Site is considered sufficient to be suitable for the application of the LBT concept. Under the LBT concept, additional quantities of organic material that are available would have value and can be placed on the Site.
5.0 LEACHATE QUALITY AND QUANTITY

Landfill investigation studies have suggested that leachate composition is inherent to the refuse composition, landfill location, and conditions created by landfill operations. However, leachate composition, particularly concentrations of organic leachate constituents, is primarily a function of the age of the landfill (McBean et al., 1995).

Reinhart (1995b) summarizes data collected from five full-scale recirculating landfills and suggests that contaminants do not concentrate extensively in leachate. However, recycled leachates have been shown to remain more concentrated than leachates derived from a conventional landfill, generally due to the decreased "strength" of leachate in conventional landfills as a result of "wash-out" (i.e., tendency of contaminants to be transported away from the site by infiltrating water) (Reinhart, 1995). A study completed in Australia suggested that leachate recirculation extended the acidic phase of leachate chemistry, and without a natural or added buffer, the low pH of the leachate would inhibit the growth of methane producing bacteria, and hence the decomposition of the waste (Magnuson, 1998). Excellent success at using a natural buffer has been attained in CRA's operating bioreactor in Tucuman, Argentina; methanogenic conditions were attained at time of closure of both bioreactor cells.

Metals concentrations in leachate also decrease as a function of "wash-out" in conventional landfills. However, in recirculating landfills, it has been found that the primary mechanism for metal removal is precipitation from solution with sulphide and hydroxide ions within the refuse. Once leachate stabilizes however, metals may re-dissolve into the leachate. Historical and projected leachate quality data for the Site indicate low metal concentrations and hence little concern for re-dissolving metals in the recirculated leachate.

Leachate recirculation dramatically reduces the stabilization time of organic constituents in leachate. Inorganic constituents, which are more conservative, do not break down and therefore remain within the landfill until pumped out and treated. However, leachate recirculation does not increase contaminant concentrations present in the landfill (Reinhart, 1995).

The theory that leachate generation begins once field capacity of the waste has been reached is not accurate due to the heterogeneous nature of waste, which causes non-uniform moisture distribution within the waste mass. Nevertheless, it can be expected that leachate flow rates will increase once field capacity has been reached. Therefore, as discussed in Section 3.0, it is imperative that the landfill system design facilitates and accommodates the additional moisture that will be generated. Possibly
the most critical component of a bioreactor landfill is the liner, which must be constructed to accommodate the additional hydraulic head associated with increased leachate flows in bioreactor landfills. As described in the November 2004 Hydrogeologic Investigation Report for the Optimization of the Site, the Site is underlain with 80 m of silt and clay fill suitable for landfill operations. This is the sort of liner that is well capable of accommodating the additional head associated with anticipated leachate volumes at the Site.

Careful monitoring of both the leachate quantity and quality are imperative to the successful application of LBT. The currently approved monitoring and inspection program for leachate quantity and quality for the Site is compatible with the LBT concept.

Expected leachate quality and quantities from the implementation of the leachate recirculation program at the Site can be accommodated under the current operation of the leachate collection system and the leachate treatment plant. In addition, the Proposed Optimized Site contingency plan includes expanding the treatment plant flow and loading capacity by approximately 50 percent to accommodate potential increases in leachate quality and quantity as a contingency.
6.0 LEACHATE VOLUME AND STORAGE

The following conditions must be considered to accommodate leachate volume and storage when utilizing leachate recirculation:

- leachate storage must accommodate precipitation on an active landfill through infiltration, runoff and evaporation during both dry and wet weather events;
- additional leachate generation will result from "short-circuiting" of leachate due to the heterogeneity in the permeability of wastes in a landfill (and potential ponding or side seeps); and
- leachate flow generated during the active landfill phase from areas not enclosed by the cover system in circumstances where the opportunity for absorption is limited.

To accommodate leachate reintroduction, on-Site leachate storage is necessary, as leachate must be reintroduced to the waste at a controlled rate to avoid leachate breakout or seeps. Ex situ storage capacity and treatment (i.e., on Site and/or off Site) is the most common option used. Leachate storage can also be carried out within the landfill itself, providing the groundwater table is both situated above the liner base to maintain a negative hydraulic gradient, and capable of preventing a large ingress of water (Yuen et al., 2001). In either case, the proper volume and size of such facilities and systems is critical for management of leachate during the early phases of operation, peak storm events, and post-closure.

Under current operating conditions, with an hydraulic trap design as suitable liner, extrapolated field capacity calculations for the Site suggests that the moisture storage capacity of the landfill is sufficient to accommodate peak moisture from the leachate recirculation program. Additionally, the on-Site leachate treatment plant, which commenced operations December 2001, further allows for additional moisture handling capacity. This plant is currently operating at approximately 25 percent of the maximum design flow. In addition, the current leachate loading of the leachate treatment plant is somewhat less than 20 percent of the plant capacity.

It is expected that over the active landfilling period for the Site, with leachate recirculation implemented, leachate flows to the leachate treatment plant can be reduced or maintained at a minimum flow rate to reduce leachate management costs.
7.0  **ALTERNATE DAILY COVER (ADC)**

Effective leachate recirculation can only be accomplished if the waste mass can be evenly wetted. The heterogeneous nature of layered waste and soil can result in "short-circuiting" of leachate through primary flow paths (i.e., horizontal movement), potential ponding, or side seeps. These conditions can then result in increased effluent leachate recirculation rates.

Reinhart (1995) cited examples of full-scale operations that have found low permeability intermediate cover to be troublesome because of the horizontal movement of leachate created (e.g., Seamer Carr Landfill, Lycoming County, Worcester County Landfill, etc.).

To operate an effective leachate recirculation system and optimize biological activity and degradation, it is important to use compatible daily cover material/technology. One ADC option is to apply materials that are permeable, as opposed to using the native clays and removing these relatively impermeable materials each day. Solid, non-hazardous wastes such as contaminated soils or other ICI wastes suitable as daily cover are often more permeable than the native clays found at the Site. Another option is to consider the use of retractable tarping technologies. Both of these ADC options have the added advantage of optimizing air space.
LANDFILL GAS GENERATION

Anaerobic LBT accelerates waste degradation by optimizing the conditions for the growth of anaerobic bacteria. Degradation of organic wastes by means of anaerobic degradation produces organic acids and ultimately LFG that is composed of approximately 50 percent carbon dioxide and 50 percent methane. The amount of LFG produced by a landfill is directly related to the organic fraction of the waste. Therefore, optimization of a landfill bioreactor system, through the introduction of moisture in the form of leachate, does not increase the overall amount of LFG produced by the landfill. Rather the application of LBT increases the initial LFG production rates and decreases the time period over which the LFG is produced. The Delaware Solid Waste Authority experienced a 12-fold increase of LFG production in a test cell utilizing recirculated leachate as compared to a conventional control cell. In addition, the Alachua County Landfill in Florida documented a doubling of LFG productions in the wet portions of the landfill, as compared to dry areas of the landfill (Reinhart, 1995). CRA is experiencing in excess of a 10-fold increase in the LFG generation rates in its bioreactor in Tucuman, Argentina throughout the first year of operation.

Due to the initial increase in LFG production when fully utilizing LBT, it is critical that the LFG collection system be sized to handle the elevated peak flows resulting from the recirculation of leachate and other moisture sources. In addition, careful monitoring of LFG quantity and composition is critical to its proper management. The benefits of this increased peak and earlier LFG production are twofold. First, if properly designed systems are in place, it can be more efficient to collect and utilize the LFG. Secondly, if a landfill is prone to having LFG migration problems, then those associated migration risks are reduced as LFG production declines more quickly than for conventional landfills. This second point does not pertain to the Site because the Site is situated entirely in clay and therefore experiences no LFG migration concerns.

Methane is recognized as a greenhouse gas (GHG) and contributes to the global warming potential of the atmosphere. The global warming potential of methane is 21 times that of carbon dioxide on a 100-year time horizon. There is future potential that a system of credits may be established to reward financially the reduction of emissions of greenhouse gases. Therefore, collection and flaring or utilization may prove to be financially attractive. With the LBT concept, additional quantities of LFG can be efficiently and economically collected and utilized during the active Site life of the landfill, thereby reducing GHG emissions to the atmosphere. Additional GHG reductions result from the energy offsets accrued by utilization. It is noted that the peak annual LFG quantities (and hence methane) produced for the Proposed Optimized Site
is estimated to be in the range of approximately 585,000 to 935,000 tonnes per year equivalent carbon dioxide (eCO₂).

Under current and proposed LBT operating conditions, the LFG management system presently proposed for the Site is capable of handling changes in expected quantities and further can accommodate the potential peak LFG production associated with the LBT concept. The first phase of the LFG management system was commissioned in September 2004. Increases in LFG quantities over time are collected via additional LFG extraction wells installed in a timely manner once a stage has been filled and the interim or final cover applied.
9.0 **LANDFILL TEMPERATURE**

Landfill temperature is determined by a balance between heat production during biodegradation (i.e., biochemical reactions) and loss of heat to the surrounding soil and atmosphere (Reinhart and Townsend, 1998). To optimize microbial activity, it has been suggested that relatively high temperatures (between 34°C to 55°C for anaerobic LBT) are required. Full-scale temperature control methods include heated air injection, which promotes aerobic respiration causing a rapid increase of temperature and ultimately methane production. These results were observed for a test cell in Brogborough, United Kingdom (Reinhart and Townsend, 1998). In Sweden (Reinhart and Townsend, 1998), recirculation of heated leachate was utilized to control landfill temperatures. In the latter case, Sorab Test Cells ("Energy Loaves") were used at the Hagby Landfill site in Taby, Stockholm, Sweden between 1989 and 1991. These measured 90 m long, 40 m wide, and 6 m high, and were filled with 8,200 metric tons of crushed solid waste which was then overlain by 30 cm of peat for insulation. To maintain optimum temperature (i.e., 35 to 40°C) and moisture content, leachate recirculation was practiced. Landfill LFG-fueled boilers heated the leachate. As well, use of waste heat from LFG-fired electrical engines is being utilized to heat the recycled leachate in Riga, Latvia.

A study conducted in Binghamton, New York, by the New York State Energy Research and Development Authority (NYSERDA) investigated the enhancement of LFG production while varying key controls. These controls were directly associated with anaerobic digestion, and included varying the moisture content, pH, temperature, and nutrients. Over the course of the 2-year monitoring period, bioreactor cell temperatures remained fairly constant, averaging 10°C. However, problems relating to the inability to distribute recirculated leachate throughout the cells, water traps in LFG lines due to settlement and problems due to freezing of pipelines were encountered.

Presently, the benefits of temperature control have not been thoroughly demonstrated. In fact, the use of temperature to control a landfill bioreactor operation is neither practical nor recommended, as described by Reinhart and Townsend (1998). This same conclusion is CRA's opinion wherein in Riga, Latvia, CRA is involved in the procurement conditions for a Swedish design for heated leachate recycle. Although the potential merits have been described in CRA (2000) and there may still be value in the concept it is not recommended for this application. Furthermore, the external ambient temperature influences the landfill temperature to a depth of approximately 2 m at maximum (McBean et al., 1995). Within the landfill itself heat generation through the active biological processes acting to decompose the waste maintain the operating temperature of the landfill. The insulating nature of the overlying layers of waste also operate to maintain the landfill temperature. It is only in small, shallow landfills that
external heat introduction methods may be usefully applied. In addition, the design of leachate recirculation systems (e.g., placement of horizontal distribution pipes, etc.) should consider the effects of external ambient temperature controls which could ultimately effect the operation of such systems.

At this time, it is not recommended that Green Lane Landfill implement any measure to control landfill temperature other than the passive heat generation inherent in landfills.
10.0 CONTAMINATING LIFESPAN

A number of landfill studies indicate that over the course of the contaminating lifespan of a landfill, distinct phases occur. These phases include the initial adjustment phase, the transition phase, the acid formation phase, the methane fermentation phase and the maturation phase (Reinhart, 1995). It has been found that these phases are common to both conventional landfills and landfill bioreactors that practice leachate recirculation. A few differences have been noted, however, between the two types of landfills.

Generally the methanogenic phase of recirculating landfills is more pronounced, as leachate constituents are not "washed-out" of the landfill, but are instead continually pumped out and reintroduced to the landfill during recirculation. However, studies show that the period needed to achieve leachate stabilization for organic constituents within the landfill is reduced for sites that recirculate their leachate. For example, the half-life of COD in a conventional sanitary landfill is generally 10 years, but has been found to be 230 to 380 days in a recirculating landfill (Reinhart, 1995). As discussed in Section 5.0, inorganic leachate constituents generally do not decline as rapidly in conventional landfills; however, these components of the leachate at the Site are lower than typical and are not considered an issue.

Leachate recirculation has also been shown to increase the rate of waste settlement within the landfill by increasing the waste density. If the settlement of a landfill is predicted and controlled, it can extend the operating life by significantly increasing the volume of airspace in the landfill. Studies suggest that leachate recirculation can reduce the time required for landfill stabilization from several decades to a few years (Reinhart and Townsend, 1998).

Since the development of the bioreactor technology is only recent, there is only limited research on the long-term effects of recirculation on the contaminating lifespan of a landfill. Trends developed from short-term studies indicate that leachate recirculation significantly reduces it. Leachate recirculation shortens the time over which the landfill matures and eventually becomes inert. By reducing the time over which leachate production and LFG production occur, the systems and staff needed to manage landfill operations can be shortened, designed on-Site monitoring controls utilized, and financial assurance requirements should be able to be decreased. It can be expected that the above benefits can be applied to the Site with the currently approved leachate recirculation program and further potential improvements from the LBT concept as applied to the landfill.
11.0 DISCUSSION

Studies have demonstrated that LBT accelerates waste degradation, enhances in situ treatment of leachate, enhances LFG production rates, increases landfill air space, reduces leachate management costs, improves leachate quality, and promotes rapid settlement of waste with the net result of earlier landfill stabilization. Limitations to the technology include reluctant regulator acceptance, limited availability of design criteria, and limited ability to maintain uniformly wet waste.

As a result of this relatively new technology, and the fact that most active bioreactor landfills have not reached maturity, design and operational criteria are still evolving. The applicability of leachate recirculation and some form of LBT at the Site represent some important opportunities for application, with concomitant benefits. Table M.1 presents a comparison of the advantages and disadvantages of the technical feasibility of LBT as they apply to the Site.
12.0 SUGGESTED IMPLEMENTATION OF LBT CONCEPT

Below is a discussion of the suggested means of applying the LBT concept at the Site by alternative levels of effort. Three potential alternative levels of effort are as follows:

- status quo;
- selected elements of the LBT concept; and
- full LBT concept implementation.

As indicated previously, the status quo includes significant elements of the LBT concept that are currently approved for the Site, including leachate recirculation and LFG management. Other significant factors of the current design and operations plan for the Site include:

- engineered facilities suitable for the implementation of leachate recirculation and hence LBT;
- hydraulic trap design and extent of clay soil stratigraphy ensures leachate mound and contaminating lifespan concerns are addressed; and
- monitoring of landfill processes and operations.

The opportunity exists to apply some additional aspects of LBT to the Site. The two biggest concerns with leachate recirculation are the ability of the liner and leachate collection system to handle additional moisture in the refuse, and the ability of the LFG collection system to collect a higher peak LFG production flow. The liner and clay soil under the Site is capable of handling the additional leachate flow and potentially higher leachate head that might result. In addition, the LFG management system will be sized and installed to handle the anticipated LFG peak flow. There are modifications and additional elements of the LBT concept that could be made to the operation of the landfill that would further enhance the successful application of this technology at Green Lane. They are summarized as follows:

i) The use of a more permeable material or a retractable cover daily cover should be considered to prevent the development of perched leachate and seeps, and to improve the ability to wet the waste uniformly.

ii) Augment the leachate distribution system with vertical injection wells in addition to the approved leachate recirculation trenches. In addition, investigate methods of pre-wetting the waste in the active area of the landfill to increase compaction efforts.
iii) The LFG collection system should be constructed immediately as each stage closes and interim or final cover placed to maximize the amount of LFG collected.

iv) Additional organic material could be diverted to the landfill to take advantage of the increased LFG flows of the LFG collection system and increase the opportunity for the utilization of LFG for direct use or energy production. Additional benefits include a reduction in GHG emissions to the atmosphere.

v) Manage the timing of stage closure and capping, installation of leachate recirculation and LFG collection components to take advantage of the combined benefit of these processes.

Full implementation of the LBT concept to the Site would require full control of the anaerobic process. In addition to the status quo activities and the additional elements of the bioreactor concept noted above, implementation of the full LBT concept (i.e., process control) at the Site would entail the following significant activities:

- revised daily and intermediate cover and material type to a more permeable material. This would allow flow through of additional water through the leachate recirculation system and accelerate the waste reaching field capacity; chemical addition to the recirculated leachate (and possibly waste entering the Site) to obtain or maintain optimized anaerobic conditions;
- installation of in situ monitoring technology to ensure process control; and
- shredding or screening of the waste to enhance biological and chemical activity as part of the process control.

It is noted, that based on the literature search and industry information, while full process control has not been demonstrated at a full scale landfill, there is no question that there are some significant potential benefits associated with the LBT. Other significant difficulties with full implementation at the Site include:

- installation of in situ monitoring technology has not matured to the point of being able to monitor reliably and inexpensively conditions in the landfill over time;
- chemical addition and shredding or screening of wastes is likely too expensive for the unproven benefits;
- current waste compaction efforts and landfill configuration based on previously finalized landfill design;
- interim and final cover design and thickness based on locally available excess soils; and
• additional moisture sources not available and volumes required prohibits use of local municipal supply.

However, given the potential benefits of the LBT concept, including LFG collection efficiency with resulting GHG reductions and earlier landfill stabilization, it is recommended that efforts be made to test elements of this concept wherever practical at the Site.
REFERENCES


United States Environmental Protection Agency (USEPA) and Buncombe County General Services Department. Educational Workshop on the Landfill Bioreactor Process, pp. 4-5, June 2001.

<table>
<thead>
<tr>
<th>Advantage</th>
<th>Disadvantage</th>
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<tr>
<td>Leachate Recirculation:</td>
<td>• No sources of additional moisture available on Site other than leachate&lt;br&gt;• Higher compaction densities may impact leachate flow and increase potential for seeps&lt;br&gt;• Winter conditions and odour concerns may limit use of surface application techniques</td>
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<tr>
<td>• Current landfill design includes leachate recirculation through horizontal leachate recirculation trenches&lt;br&gt;• Recirculation in the active filling area can be tested to evaluate for odour concerns or seeps&lt;br&gt;• Higher rate of settlement at site and hence additional waste disposal opportunity</td>
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<tr>
<td>Organic Content:</td>
<td>• Currently, Green Lane Landfill accepts a relatively low fraction of organic waste than typical MSW landfills</td>
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<td>• Potential to increase organic content of the waste by allowing compostable material, sewage sludges, and other high organic content wastes&lt;br&gt;• Future increases in proportion of MSW waste for the landfill</td>
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<tr>
<td>Leachate Quality and Quantity:</td>
<td>• No wash-out of conservative leachate constituents including metals. This is not considered significant as metals concentrations in the leachate at the Site are lower than that typically found at MSW landfills</td>
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<td>• Faster degradation of organic leachate constituents&lt;br&gt;• Potentially lower overall leachate management costs</td>
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<tr>
<td>Leachate Volume and Storage:</td>
<td>• Increased effort to install and distribute recirculation leachate in a stage</td>
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<tr>
<td>• Liner is capable of handling potentially higher leachate head with the hydraulic trap type landfill&lt;br&gt;• Unsaturated space is available for recirculating leachate in waste mass</td>
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<tr>
<td>Alternative Daily Cover:</td>
<td>• Use of impermeable daily cover may create perched leachate conditions which may potentially inhibit the success of LBT</td>
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<tr>
<td>• Potential for implementation of ADC for increased permeability for more effective leachate recirculation&lt;br&gt;• Potential for landfill airspace saved</td>
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<tr>
<td>Landfill Gas Generation:</td>
<td>• Increased effort to install and collect LFG extraction wells in a stage</td>
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<tr>
<td>• Current landfill design includes LFG collection system with capacity to collect additional LFG generated by recirculating leachate&lt;br&gt;• Increased GHG credits (if available)&lt;br&gt;• Increased LFG collection quantity available for utilization</td>
<td></td>
</tr>
<tr>
<td>Contaminating Lifespan:</td>
<td>• None identified</td>
</tr>
<tr>
<td>• Potential decreased contaminating lifespan with concomitant opportunity to reduce financial assurance requirements</td>
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