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Yolo County, California

A Beneficial Investment in Trash

Controlled Landfill Bioreactor Project

Urban Consortium Energy Task Force

Yolo County Planning & Public Works Department
Division of Integrated Waste Management

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Bioreactors Make Environmental Cents

Controlled Landfill Bioreactor Project

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

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II. EXECUTIVE SUMMARY

The Yolo County Division of Integrated Waste Management decided to investigate the controlled landfill bioreactor, a progressive new technology for solid waste management, to address the potential long-term impacts of current landfill practices. A controlled landfill bioreactor works by regulating the conditions in a landfill cell to promote accelerated waste decomposition and generation of landfill gas. The concept is to *actively manage* the degradation of landfilled waste to reduce the toxicity of the leachate and to decrease the time required for stabilization of the waste. By reducing the pollutant load and stabilizing the waste early, during the 30-year period when federally required enforcement and monitoring systems are required, the risk of future groundwater contamination is greatly reduced.

The Purpose:

To actively manage the degradation of landfilled waste in order to reduce the toxicity of leachate and to decrease the time required for stabilization of the waste.

Numerous laboratory and field studies on leachate recirculation and controlled landfill bioreactors have been conducted in the U.S. and abroad. These studies indicated that leachate recirculation lowered the pollutant strength of leachate more quickly and reduced peak pollutant levels. Although laboratory and pilot studies have been conducted, comprehensive data to support and quantify the benefits of this technology still needs to be acquired before regulatory acceptance. Therefore, Yolo County constructed two demonstration cells -- *a control cell* and *an enhanced cell*. The control cell employs conventional landfilling methods, while the enhanced cell uses the controlled landfill bioreactor technology. The enhanced cell has a liquid recirculation system to promote accelerated waste decomposition. The system works by first adding water until the waste reaches field capacity. Then, the leachate that is subsequently produced is recirculated back into the cell to continue wetting the waste. The leachate provides nutrients, as well as moisture, which helps to increase microbial decomposition of the organic portion of the landfilled waste.

A comprehensive monitoring plan was developed to ensure all aspects of the project related to waste decomposition were tracked. After two years of operation, project results are promising for commercialization of this technology. The favorable conditions provided for waste decomposition are evident by the leachate pollutant strength which was reduced from peak levels to low, nearly stabilized levels, after leachate recirculation. Additionally, the enhanced cell produced a total gas volume twice that of the control cell and there was nearly seven times more settlement in the enhanced cell than in the control cell.

To further promote commercialization of this technology, the County completed an economic analysis to evaluate methane costs and greenhouse cost-effectiveness of controlled landfill bioreactors. This information will assist landfill owners in evaluating the incremental costs and benefits of full-scale implementation of a controlled landfill bioreactor. A summary of the regulatory status of controlled landfill bioreactors is also presented in this report.

III. CONCEPT

Historically, common practice was to take garbage to the local *"dump"*, which was usually an open pit or ravine. However, as the environmental impacts of these practices on water and air quality became more pronounced, new regulations were developed. Today, sanitary landfills are the most common approach to waste disposal in the U.S. Waste received at a sanitary landfill is placed in layers, or lifts, approximately 15 to 20 feet thick. The waste is compacted and covered daily with soil or other approved materials. After the maximum permitted height of the landfill is reached, regulations require a cover be placed on the modules to keep rainwater out and landfill gas in.

Sanitary landfills have become the standard method of disposal due to the increasing regulations that address environmental impact issues by increasing containment regulations for landfilled waste. The enactment of the Resource Conservation and Recovery Act (RCRA) and Subtitle D require landfilled waste to be contained by a composite base liner and the modules to be constructed with a leachate collection and removal system. The composite base liner, typically consisting of an impermeable plastic membrane and a compacted clay liner, prevents liquid, called leachate, from entering the groundwater supply. The leachate collection and recovery system removes leachate from the landfilled waste after it drains to the base of the unit.

Environmental issues related to landfills have been addressed historically by implementing regulations that require increased waste containment.

Leachate forms in a landfill as waster such as rainfall slowly percolates through the waste. Waste that is relatively young and fresh will generate leachate with very high pollutant strength. As the organic material decomposes and the waste stabilizes, the leachate pollutant strength reduces significantly. Waste stabilization occurs when gas production rates are less than five percent of peak value and when leachate has chemical oxygen demand (COD) below 1000 mg/l and biological oxygen demand (BOD) below 100 mg/l (Reinhart and Townsend, 1997). Additional parameters that can indicate waste stability include BOD/COD ratios less than 0.1, waste cellulose/lignin ratios less than 0.2, low biological methane potentials (less than .045 m^3/kg volatile solids added) and a dark, sludge-like appearance of the waste (Reinhart and Townsend, 1997).

Due to the greenhouse gases released during waste decomposition, air quality is another area of significant environmental concern for landfills. Greenhouse gases are the principal atmospheric gases that act to warm the earth. The process functions similar to the way a greenhouse warms to temperatures greater than the outside air. Light energy from the sun passes through the Earth's atmosphere and is absorbed by the Earth's surface then re-radiated into the atmosphere as heat energy. Some of this heat energy makes its way out of the atmosphere, while some of the heat is held at the Earth's lowest atmospheric layer by atmospheric gases that block its escape. This natural process regulates the Earth's temperature. However, many scientists believe that the accumulation of excess greenhouse gases, produced by human activities, will further slow the passage of re-radiated heat through the Earth's atmosphere and contribute to global warming. The atmospheric gases that have the most influence on this system are primarily carbon dioxide, methane, and nitrous oxide.

Landfill gas usually consists of approximately 50% carbon dioxide and 50% methane. Both are greenhouse gases. In active landfills, the internal pressure is usually greater than atmospheric pressure, therefore, landfill gas is released not only by diffusion but also by convective or pressure-driven flows. At lateral distances of up to 400 feet from unlined landfills, methane and carbon dioxide have been found at concentrations up to 40 percent stabilize (Tchobanoglous, et al., 1993). To prevent landfill gas from leaving the landfill and rainfall from entering, final cover systems using impermeable liners are becoming standard, however they are not required.

The intent of current regulations is to prevent the generation of landfill by-products by maintaining the waste at conditions that are as dry as possible. Although these regulations are to protect the environment, they only prolong the problem. Dry conditions in a landfill result in slow waste decomposition. Studies have shown waste landfilled under current practices decomposes over an extended period of time, and may require up to 80 years to stabilize (Tchobanoglous, et al., 1993; Augenstein and Pacey, 1991). The Code of Federal Regulations, part 258.61, requires post closure care, including monitoring and maintenance, to be conducted for only 30 years. The only exception is if the Director of an approved State agrees to decrease or increase that period based on sufficient protection of human health and the environment. There can be extreme variations in the period of time that maintenance will be required, therefore, federal and state regulations have prescribed minimum time periods for long-term care ranging from 20 to 30 years (Tchobanoglous, 1993). Many states have also passed legislation requiring the operator of a landfill to put aside enough money to maintain a closed landfill into perpetuity (Tchobanoglous, 1993).

In effect, current practices act to entomb landfilled waste until some point in time when the containment system fails and moisture is able to enter the landfill. Several situations could lead to leakage including, manufacturer's defects, seam failure, destructive weather influences or other unpredictable factors. Subsequently, waste decomposition would quickly accelerate, generating landfill gas and high pollutant strength leachate. Additionally, if a failure were to occur after the post-closure period, when monitoring requirements are no longer mandated, there would be potential for negative environmental impacts to go undetected.

Conventional sanitary landfills that place impermeable bottom and cover liners, without controlling internal landfill conditions, suspend waste degradation. Controlled landfill bioreactors, on the other hand, not only suppress possible environmental hazards like greenhouse gas emission or groundwater contamination, they also increase waste degradation and therefore allow increased methane production rates, decreased leachate pollutant strength, increased waste stabilization, and decreased post-closure maintenance costs.

The Controlled Landfill Bioreactor

The controlled landfill bioreactor is a technology used to accelerate waste decomposition. This technology works by improving the conditions required for microbial biodegradation processes. Like any other organism, the microorganisms that degrade waste require specific ranges of environmental conditions. Moisture, temperature, pH, nutrient availability, and several other factors can effect microbial activity. Of these factors, moisture is the most important and it is the easiest to manipulate in a landfill. Therefore, liquid addition is the method most commonly used to enhance waste degradation.

The controlled landfill bioreactor offers numerous benefits for solid waste management. Most importantly, it *actively* manages waste in the near term. The waste in a landfill bioreactor is stabilized within five to ten years, while monitoring systems are still required, preventing severe problems from occurring unexpectedly after closure. The benefits of a controlled landfill bioreactor include:

- Increased methane generation rates resulting in economic feasibility as a green energy source;
- Decreased leachate treatment costs due to decreased leachate pollutant strength;
- Increased settlement which provides additional landfill space and landfill life extension;
- Shortened stabilization periods, allowing efficient dedication of the land to more beneficial uses;
- Reduced post-closure maintenance expenses;
- Reduced greenhouse gas emissions because of the increased gas capturing efficiency.

Comparing Bioreactor Projects

Numerous laboratory and field studies on leachate recirculation and controlled landfill bioreactors have been conducted in the U.S. and abroad. These studies indicated that leachate recirculation lowered constituent levels such as chemical oxygen demand (COD) and total volatile acids (TVA) in a shorter time and also reduced their peak levels (Reinhart and Townsend, 1997). The effect of amendments, pH management, and waste shredding varied between studies depending on site-specific conditions. The following is a summary of some leachate recirculation projects performed to date.

Delaware Solid Waste Authority

The Delaware Solid Waste Authority began employing one of the first large-scale applications of recirculation at its Central Solid Waste Management Center (CSWMC) in Sandtown, Delaware. CSWMC began employing leachate recirculation in 1982 on cells that were built in 1980 as a method to treat the vast quantities of leachate produced from close to 30 acres of waste (Vasuki, 1993). Several recirculation methods were tested at this facility, including surface flooding, spray irrigation, vertical recharge wells, and tiled infiltrators. Initially, the techniques were not applied in a scientific manner and the information available about the project is primarily qualitative, however, the project is invaluable as a preliminary evaluation of recirculation techniques.

Surface flooding was determined “not worth the effort” due to odor problems and the mess that it made (Vasuki, 1993). Spray irrigation proved unpredictable and unsafe due to aerosol carry over during shifting winds (Vasuki, 1993). The irrigation system was employed on a closed section of landfill, where it also killed the existing vegetation and created odor problems.

Vertical recharge wells were used to allow leachate to trickle down into the landfill and act as an aerobic filter (Vasuki, 1993). This technique was efficient compared to previous attempts, however, the pea gravel that was used to fill the wells clogged in the presence of leachate precipitates (Vasuki, 1993). Wells were redesigned for recirculation by using large size stones in a four-foot diameter perforated concrete cylinder (Vasuki, 1993).

The next system designed for recirculating leachate used “infiltrators” in a tile field that spread the leachate into the waste from below the final cap (Vasuki, 1993). The system incorporated valves that allowed control of liquid inflow (Vasuki, 1993). This system worked well.

Gas generation rates are unavailable for this project, however, favorable conditions for waste decomposition were evidenced by low organic leachate levels after about seven years (Reinhart and Townsend, 1997). CSWMC qualitatively concluded that leachate recirculation increased waste breakdown, settlement, and gas generation while simultaneously decreasing the costs of leachate treatment (Vasuki, 1993).

Sonoma County, California

The Sonoma County Project was one of the first studies on liquid addition and leachate recirculation. Five pilot-scale demonstration cells were constructed. Each cell contained approximately 500 tons of municipal solid waste and each had a clay cap (EMCON, 1975). The cells were 49 feet by 49 feet by 10 feet deep. Various enhancement techniques were applied to each cell, as shown in Table 1. Cell A was the project control and therefore did not receive liquid Cells B and E were initially brought to field capacity through the addition of water and septic pumpings, respectively, but liquid additions did not continue. Cell C received daily additions of water, whereas, Cell D received daily additions of leachate (leachate recirculation).

Table 1. Sonoma County project design.

Cell	Initial Water Addition	Continuing WaterAddition (gal/d)	Leachate Recirculation (gal/d)
A	**None, Project Control**	**none**	**none**
B	**Brought to Field capacity,** with 41,000 gallons of water	**none**	**none**
C	**none**	**200-1000**	**none**
D	**none**	**none**	**500-1000**
E	**Brought to Field capacity,** with 27,200 gallons of septic tank pumpings	**none**	**none**

Between November 1971 and April 1974, leachate quality, gas composition and landfill settlement were the parameters monitored to determine the relative levels of waste stabilization. Results of the project indicate the level of waste decomposition was higher in the cells where liquid was added continually (Leckie and Pacey, 1979).

Landfill gas composition from Cell C and Cell D suggested favorable conditions for waste decomposition because the gas compositions stabilized at 50 percent methane. On the other hand, unfavorable conditions for methane generation were indicated by the control cell, Cell A, and Cells B and E. The gas composition for these three cells was similar, all remained near 90 percent carbon dioxide (EMCON, 1975). Generally, gas composition indicated that liquid addition enhanced conditions for waste decomposition.

The leachate composition in both Cell C and D showed declining organic strength, however, Cell D provided the most rapid decline in chemical oxygen demand (Reinhart and Townsend, 1997). The daily addition of water into Cell C, without the recirculation of that water, generated large volumes of leachate that required treatment (Reinhart and Townsend, 1997). On the other hand, the daily addition of water and the recirculation of the leachate proved a beneficial means of treating the leachate *in situ*.

Landfill settlement provided significant results for leachate recirculation. The only leachate recirculation cell, Cell D, showed a 20 percent reduction in height, while other cells showed only a 7.6 percent reduction in height (Reinhart and Townsend, 1997). These settlement results, along with the gas and leachate composition results, show that while the addition of water can help decomposition, the greatest benefit is realized through leachate recirculation.

Mountain View Landfill, California

The Mountain View Project is one of the earliest, and most comprehensive, landfill enhancement projects. As an expansion of the Sonoma County Project, this project explored the underlying biological mechanism of degradation by varying those environmental components that are thought to effect the activity and survival of the anaerobic microorganisms. Several environmental conditions were considered including moisture, pH buffer addition, bacterial seeding through sludge amendments, and leachate recirculation.

Six demonstration cells were constructed and each was filled with an average of 5,830 tons of municipal solid waste (EMCON,1987). The cells were 100 feet by 100 feet by 47 feet deep. The enhancement regime applied to each cell is outlined in Table 2. Cell F was the project control cell and did not receive any enhancement. Cells A, B, C, and E received sludge and buffers and Cell D received buffer only. Partial leachate recirculation was applied to Cell A only. From June 1981 to December 1985, a variety of parameters were monitored to evaluate each enhancement regime.

Table 2. Mountain View project design.

Cell	Water	Sludge	Buffer	Leachate Recirculation
A	**Field capacity** Added 458,000 gallons	X	X	X
B	**none**	X	X	no
C	**Field capacity** Added 451,110 gallons	X	X	no
D	**Below field capacity** Added 69,640 gallons		X	no
E	**Below field capacity** Added 63,100 gallons	X	X	no
F	**None**, project control	no	no	no

Although the project is known as one of the most comprehensive projects, some of the project results conflict with other studies that use leachate recirculation techniques (Reinhart and Townsend, 1997). For example, the total reported gas production rates were lower than the rates obtained in other studies. Several other anomalies occurred with this experiment. One of the driest cells, Cell D, *reportedly* generated the most landfill gas. Cell A produced less gas than Cell C in spite of the fact that the cells were identical except for the partial recirculation of leachate in Cell A (Reinhart and Townsend, 1997).

Discrepancies are attributed to at least two very significant factors, lack of moisture control and gas leaks (which led to incomplete gas capture). As shown in Table 3, refuse analysis proved that there was no effective control over moisture content due to excessive water infiltration into the test cells. There were numerous discrepancies between measured and calculated gas production rates; inconsistencies in gas production data were attributed to gas leaks. The pathways of moisture infiltration and gas escape were probably the same, as indicated by the fact that the cells with higher infiltration had lowered measured gas production rates (Reinhart and Townsend, 1997).

Table 3. Summary of Mountain View project results.

Cell[1]	Moisture Content (%)	Landfill Gas Volume at day 1597 (100,000 ft^3)	Volitile Solids Content (%)	Biochemical Methane Potential (scf CH_4/lb dry refuse)	Cellulose (%)	Lignin (%)	Carbon to Nitrogen Ratio	Carbon to Phosphorus Ratio
A	69	111	32	0.35	16	13	13:1	6593:1
B	54	97	43	1.57	26	14	20:1	945:1
D	33	264	51	1.93	33	14	26:1	1345:1
F (control)	40	223	44	1.48	27	14	27:1	1169:1

Table adopted from Reinhart

1. Cells C and E were not analyzed for Biochemical Methane Potential, therefore they are not presented in this table.

Contrary to the gas generation data, a biochemical methane potential analysis of refuse samples indicates that the leachate recirculation cell had actually degraded more than the control cell. Results are shown in Table 3 above. The recirculation cell had the lowest potential (0.35 scf CH_4/lb dry refuse) for further methane production and the control cell had a high potential (1.48 scf CH_4/lb dry refuse) (EMCON, 1987). The highest potential was found in the cell that had only negligible water infiltration, Cell D, which had a potential of 1.93 scf CH_4/lb dry refuse. These results help to prove that other data were inaccurate due to cell leaks.

Despite many difficulties experienced during this project, final chemical analysis of refuse samples provided evidence of leachate recirculation success. Cell A, which used leachate recirculation, had a relatively low volatile solids content, low cellulose content, low carbon-to-nitrogen ratios, and high carbon-to-phosphorus ratios. The results for these parameters provide evidence of faster stabilization (Reinhart and Townsend, 1997). By using "loss of volatile solids" to find calculated average methane production, the refuse analysis suggests that methane gas generation was enhanced by moisture, sludge addition and leachate recirculation (Reinhart and Townsend, 1997).

Brogborough, United Kingdom

Based on the results of previous controlled landfill bioreactor studies, the objective of the Brogborough study was to further investigate the effect of waste density, air injection, waste amendments, and leachate recirculation (Croft and Fawcett, 1993). The project consisted of six demonstration cells filled with between 16,500 and 22,000 tons of waste (Reinhart and Townsend, 1997). Cell 1 was the project control while various enhancement techniques were applied to the remaining five cells, as outlined in Table 4.

Table 4. Summary of Brogborough project results.

Cell	Enhancement Technique	Refuse (ton)	Volume Landfill Gas (m^3/t/d)
1	Project Control	15,130	0.0159
2	Low density waste placement	13,980	0.0132
3	Water addition and leachate recycling	14,270	0.0118
4	Air injection system in place	14,400	0.0184
5	Sewage sludge addition plus supply of water	16,870	0.0192
6	Commercial and industrial waste addition	14,980	0.0205

Based on the landfill gas flow rates and methane composition, Cell 6 produced the largest quantity of methane gas, showing that a mixture of nonhazardous industrial and commercial waste helped to promote degradation. This conclusion would of course depend on the typical industry waste brought to a specific landfill.

As methane production increased in each cell, the leachate composition decreased in organic strength and the pH level increased (Croft and Fawcett, 1993). Cells 4, 5 and 6 had the largest settlement rate indicating favorable conditions for waste decomposition (Croft and Fawcett, 1993). Settlement significantly impacted the integrity of the cap and gas recovery piping, which may have affected the gas production results (Reinhart and Townsend, 1997).

IV. THE YOLO COUNTY CONTROLLED BIOREACTOR

To address the potential long-term impacts of current landfill practices the Yolo County Division of Integrated Waste Management decided to investigate the controlled landfill bioreactor as a new method for managing solid waste. Previous studies have provided Yolo County with an invaluable information regarding problems and successes that were encountered during field application of bioreactor technology.

Framework

The Yolo County Controlled Landfill Bioreactor project controls the conditions required by microorganisms to decompose landfilled waste by increasing the moisture content of the waste. Initially, water is added until leachate is produced. Then, the generated leachate is recirculated back into the waste. This technology is related to an accepted practice known as leachate recirculation (Augenstein, 1998). However, typical leachate recirculation may not necessarily monitor the amount or rate of leachate injection, rather it is used as a means of leachate disposal. In the case of a controlled bioreactor, the system is closely monitored to control the rate of application and to ensure that the waste does not exceed its moisture-holding capacity.

Objectives

The Yolo County Bioreactor was designed to test the operation of a landfill as a biological treatment system. The landfill internal environment in the test cell is manipulated, by adding and recirculating liquids, to achieve rapid biological stabilization. This leads to accelerated methane generation and maximizes landfill gas capture (Yazdani, 1997).

The information provided by this experiment on liquid management in a landfill cell will provide valuable data for regulatory agencies to make decisions that are more informed. Additionally, a better understanding of the operation and performance will aid landfill owners as they evaluate the benefits of using controlled landfill bioreactor technology. The objectives of the project are listed below.

- Demonstrate substantially accelerated landfill gas generation and biological stabilization while maximizing gas capture.
- Estimate the landfill life extension that can be realized through rapid waste decomposition.
- Demonstrate that the recirculation of leachate is an effective leachate treatment strategy.
- Provide regulatory agencies with information to develop guidelines for the application of this technology.
- Measure and track the movement of moisture through landfills.
- Disseminate information resulting from the continued monitoring of the project.
- Monitor the biological conditions within the landfill cells.
- Assess the performance of shredded tires as a medium for the transfer of landfill gas to collection points.

Demonstration Setup

The Yolo County Bioreactor project consists of two demonstration cells, a control and an enhanced cell. The *control cell* represents a conventional landfill. The *enhanced cell* is set up as a controlled landfill bioreactor, designed with a leachate recirculation system to accelerate waste decomposition. Both cells are 100 x 100 x 40 feet in volume, containing approximately 9,000 tons of municipal solid waste each. This is large enough to duplicate the compaction, heat transfer and other characteristics of large-scale landfill cells.

Constructed as part of a larger landfill module, each cell is surrounded by compacted clay levees and covered with a low-density polyethylene (LDPE) geomembrane to prevent gas or liquid migration. Similar to conventional landfills, a Subtitle D composite base liner was placed at the base of each cell. Because liquid was added to the enhanced cell, an additional base liner was constructed below the primary liner. This secondary liner system serves as a leak detection system.

Between April and October 1995, the cells were filled with about 9,000 tons of municipal solid waste. Large bulky items such as couches and mattresses were excluded due to the project size. Waste was placed in five-foot-thick lifts with one foot of alternative daily cover, for a total of nine lifts. Chipped greenwaste was used as alternative daily cover instead of soil to facilitate moisture movement within the waste.

Monitoring Systems.

Both cells were highly instrumented to monitor a variety of parameters related to waste decomposition. There are temperature and moisture sensors placed at three different instrumentation levels in the control cell and four in the enhanced cell. Two kinds of moisture sensors were used as an effort to avoid problems that occurred in other experiments. The 56 moisture sensors and 24 temperature sensors are connected to a datalogger which records the sensor readings at set time intervals and allows remote downloading of data via a remote telemetry unit.

Gas Collection.

Landfill gas is collected from each cell through vertical and horizontal wells. Two types of vertical wells were constructed, a conventional well using gravel as a gas collection medium, and an experimental well using shredded tires. Overlying the surface of each cell is a horizontal gas collection system. This horizontal system is an innovative design comprised of shredded tires. Landfill gas that is not collected by the vertical wells is captured in the horizontal tire layer, thereby preventing surface greenhouse gas emissions.

Liquid Addition.

Initially, supplemental water was added to the enhanced cell, which was subsequently followed by recirculation of the leachate. No other enhancement techniques were applied. The simple enhancement operation achieves two benefits. First, the benefits of supplemental water addition and leachate recirculation are easily quantified; and second, it requires minimal operational changes for full-scale application.

Liquid is added to the enhanced cell through an array of infiltration trenches constructed as part of the horizontal gas collection system in the cell. Once leachate is produced in the cell, it drains to a manhole where it is recirculated back into the cell. Separate manholes were constructed for the enhanced and control cells. Meters were placed on the liquid inputs to the cell to quantify the volume of leachate it generates.

Major Tasks-Methodology

A comprehensive monitoring plan was developed to ensure all aspects of the project related to waste decomposition were tracked. Major tasks performed are described below, as well as the monitoring schemes for each task. The outcome of these tasks are presented in the "results" section.

Task 1. Leachate Management

The strategy used to accelerate waste decomposition and landfill gas generation was to increase the moisture content of the relatively dry waste placed in the enhanced cell. This was done through the addition of supplemental liquid or groundwater. Ideally, groundwater should be added until the waste is unable to hold anymore. This is the field capacity of the waste. The onset of leachate generation may be one indication that field capacity has been attained. However, it is not the only criterion because liquid may travel through the waste via preferential pathways without uniformly wetting the waste.

Groundwater addition to the enhanced cell started on October 23, 1996. A total of 377,690 gallons was added between October 23, 1996 and April 15, 1997. At the start of liquid addition to the enhanced cell, the moisture sensor readings were used to track the initial wetting front. Control valves were placed on the inlet to each infiltration trench to control where the liquid was applied. Groundwater addition was stopped when the volume of leachate produced was 50 percent of the groundwater volume originally added to the cell. After the groundwater addition was stopped, only the generated leachate was recirculated back into the cell. Leachate recirculation continued until December 9, 1998. Monitoring is continuing to determine the time when leachate generation will cease.

Tasks 2 and 3. Leachate Composition Analysis and Field Monitoring

Leachate composition is one parameter used to evaluate the rate and stage of waste decomposition. Therefore, leachate analyses were performed throughout the project. Waste decomposition and landfill gas generation occur in five sequential phases. These phases are I) Initial, II) Transition, III) Acid, IV) Methane Fermentation, and V) Maturation (Tchobanoglous et al, 1993). In phase I, air is still trapped within the waste allowing biological decomposition under aerobic conditions, as evidenced by the initial elevated waste temperatures. In the second phase (Transition Phase), oxygen is depleted and anaerobic conditions begin to develop, resulting in the start of the Acid Phase. At this stage, the pH of the leachate drops to a value of five or lower, heavy metals are solubilized, and COD increases significantly due to the dissolution of the organic acids in the leachate. In phase IV, both methane and acid formation proceed simultaneously, although the rate of acid formation is considerably reduced. Waste decomposition and landfill gas production both continue until the Maturation Phase is reached. In the Maturation Phase, most of the waste is stabilized and landfill gas generation is nearly complete.

Anaerobic conditions, of the Transition phase, can be induced and made more efficient by the addition and recirculation of liquid in the waste. Anaerobic conditions created within waste allow methane-producing microorganisms, called methanogens, to thrive. As the methanogens consume the waste, methane is produced as a by-product. Gas collection systems extract the gas to prevent its escape to the atmosphere. If the equipment is in place, the gas can be converted to energy. The better the landfill conditions are for methanogens, the more active they are and therefore, the faster they are able to produce methane and the faster the waste is stabilized.

By accelerating waste decomposition using supplemental liquid additions, the methane generation phase occurs earlier, and the waste stabilizes in a shorter time. Complete waste stabilization and landfill gas generation in the Yolo County Project should be reached within 5-10 years. This is a immense reduction in time as compared to conventional landfills, where waste stabilization can vary between 10-80 years, or even longer (Tchobanoglous et al., 1993).

Monitoring. Leachate samples were collected regularly from both the control and enhanced cells. Samples were analyzed for typical physical, chemical, and biological water quality parameters. Figure 1 shows sampling process. Due to the importance of the leachate characteristics during the initial phase, leachate chemical analyses were performed weekly for the two first months of supplemental liquid addition, in order to detect any changes that may occur initially. Once the supplemental liquid addition stopped, the sampling frequency was reduced to once every two weeks for the first year, and quarterly thereafter.

Figure 1. Field equipment used to take leachate field parameters.

Task 4. Gas Composition Monitoring

Landfill gas is composed of principal gases, which are found in large amounts, and trace gases, which are present in very small amounts. Principal gases include ammonia, carbon dioxide, carbon monoxide, hydrogen, hydrogen sulfide, methane, nitrogen and oxygen (Tchobanoglous et al., 1993). However, the largest constituents of landfill gas are methane and carbon dioxide, which are typically present at levels between 40 and 60 percent. These percentage distribution between the gases are used to quantify the energy potential of the gas and provide further insight concerning bacterial activity between the two demonstration cells.

Monitoring. Landfill gas produced from each cell was analyzed for principal gases. Gas collected from each sample port is analyzed by gas chromatography, using a MTI model P2000. Analyses of gas were performed once per week in the first eight months of operation and once every two weeks thereafter.

The gas volume and methane percentages are corrected for air intrusion by comparing the average nitrogen concentration in the total flow. The difference between these concentrations is assumed to be the excess nitrogen that results from air that was pulled into the horizontal collection system through surface leaks. The vertical and horizontal gas collection systems are not hydraulically connected. Therefore, it is assumed that the nitrogen concentration in the vertical wells is representative of the gas produced by the cell. The volume of air that has infiltrated into the collection system is estimated by using the excess nitrogen concentration. The corrected methane percentage is determined by subtracting the volume of air from the total gas volume.

Task 5. Landfill Gas Flow and Pressure Measurement

Two high-precision, temperature-compensated, gas flow meters were installed to measure the gas volumes generated from the control and enhanced cells. Landfill gas generated from each cell is collected by the vertical and horizontal wells. A slight vacuum applied to each cell withdraws the gas and transfers it to the main gas collection system for energy generation at a methane gas plant located at the landfill. As the gas leaves each cell, it passes through the separate flow meters for continuous measurement. The landfill gas flow rate is determined using the cumulative gas flow measurements.

The total gas volume and gas composition are used to estimate the volume of methane gas generated by each cell. This value helps determine the potential increase in energy associated with a controlled landfill bioreactor. Upon completion of the landfill gas collection system, a vacuum was applied to both cells. Ideally, the vacuum should be maintained so that the extraction rate is the same as the gas generation rate. This prevents overdrawing atmospheric air into the cell through potential leaks or allowing a buildup of pressure that might cause excessive ballooning and damage to the surface liner.

Monitoring. Gas flow measurements have been taken continuously since June 1996. These measurements are corrected for both pressure and air intrusion; for details please see the correction calculation in Appendices B and C. The vacuum applied to each cell is measured using a hand-held digital manometer.

Task 6. Surveying of Demonstration Cell Surface

Landfill decomposition results in the transformation of biological solid waste into gas, thereby reducing the volume of the waste and creating additional landfill space. Accelerating the landfill waste decomposition rate could potentially extend the landfill life by 20 percent through the placement of additional waste before landfill closure (Pacey, 1982).

Monitoring. Settlement surveys are performed periodically (every three to six months) to determine the degree of waste decomposition and landfill life extension. Changes in the surface elevation of each cell were monitored by using settlement markers that were welded to the surface liner during construction. They indicate approximate downward movement only, not horizontal shifts.

A total of ten settlement surveys were performed between May 1996 and September 1998. Surveys are conducted using a Lietz Sokkisha automatic level Model C3-A. There are 24 settlement markers on the enhanced cell and 23 markers on the control cell. The first survey conducted in May 1996 provides the base elevation. The base elevation is then compared with subsequent survey data to determine the amount of settlement. The results of individual settlement markers are averaged to determine cell settlement.

Task 7. Data Management/Analysis/Interpretation

During construction, the demonstration cells were carefully instrumented with sensors that measure temperature, moisture content and hydrostatic head on the base liner These sensors are connected to a data logger for continuous automatic measurement. The recorded information is then sent via a remote telemetry unit (RTU) to the Yolo County main office, where it is downloaded and transferred to a database for further analysis. Leachate and gas volumes are manually monitored as described above.

Task 8. Maintenance Issues

Maintenance issues have been an important part of the project's operation and maintenance will continue until project goals are achieved. Some of the main issues encountered during the project are summarized below.

1. Accelerated settlement achieved in the enhanced cell has caused several maintenance problems. Rainwater tends to accumulate and pond in the low areas on the surface liner. Temporary drainage paths were constructed to facilitate drainage off the surface liner. As the settlement increased, it became harder to drain the ponded water off without the aid of a pump. A portable submersible pump was purchased to drain the rainwater off the cell area. Settlement has also caused the surface liner to pull tight in areas. These sections are closely monitored for leaks and will be repaired as needed.
2. Settlement of the clay levee has caused an elbow joint in the recirculation pipeline to break twice. The elbow joint was repaired both times with county personnel and will be monitored once leachate recirculation starts again. A thrust block will be added to support this joint
3. There is a lack of material supporting the clay levee from below where trucks are driven which has caused compaction and settlement issues where the gas collection pipelines are located. Thus, the gas pipeline on the enhanced cell has required leveling to facilitate proper drainage of the landfill gas condensate. The gas meter foundation pads also require periodic leveling to ensure proper meter operation.
4. In June 1998, the landfill gas generation in the control cell decreased to almost zero and there were elevated nitrogen levels. Therefore, the vacuum applied to the cell was stopped. The cell has been watched closely for possible leaks. Monitoring continues to determine the explanation.
5. Originally, sandbags were placed on the cell surfaces to weigh down the exposed surface liner. Ultra-violet light caused the sandbags to rapidly deteriorate, causing sand to spill onto the liner. Subsequently, the sandbags were replaced with rimmed tires. To protect the surface liner, a woven geotextile was placed over the liner prior to the tire placement.
6. During the winter season, fluctuations in the barometric pressure caused the surface liner of both cells to balloon excessively. This required increased monitoring and adjustment of the applied vacuum. Replacing the sandbags with tires, which weighed more, reduced the ballooning.
7. A third gas meter was installed on the main gas line following the enhanced and control cell meters. This meter measures the total flow from both cells and is used to calibrate the individual meters.

Task 9. Workshops

Two one-day workshops were conducted to promote and disseminate information on enhanced landfilling. Major discussion topics included full-scale application of a controlled landfill bioreactor, design, construction, and operational issues related to leachate recirculation and accelerated methane generation, environmental impacts and benefits, regulatory barriers, and economics. An overview of each workshop is summarized below.

The first workshop and panel discussion was presented as part of the Solid Waste Association of North America (SWANA), 3rd Annual Landfill Symposium in Palm Beach Gardens, Florida. A white paper entitled, "The Controlled landfill bioreactor: An Innovation in Solid Waste Management", was also presented as part of a bioreactor workshop. The workshop was well received by approximately 250 people in the solid waste industry. Another panel discussion on controlled landfill bioreactors was held at SWANA's March 1999 Landfill Gas Symposium in Orlando, Florida.

The second workshop was a one-day workshop and panel discussion at the City of Albuquerque Public Works Department in June 1998. The City of Albuquerque organized the workshop, which included presentations by Yolo County, City of Albuquerque, University of New Mexico, and the State of New Mexico Department of Environment. County personnel and partners in the solid waste industry presented the controlled landfill bioreactor panel discussion.

Task 10. Economic Analysis

An economic analysis was conducted to determine the costs of methane fuel, as well as the greenhouse cost-effectiveness from controlled landfill bioreactors. Information on these issues will assist the solid waste industry when evaluating the incremental costs associated with full-scale application of this technology. As part of the analysis, current regulations, and policies relating to controlled landfill bioreactors is discussed. The analysis is presented in a later section.

Task 11. Technology Transfer and Information Dissemination

For controlled landfill bioreactors to move toward commercialization, the data from this demonstration project, methodology used in its interpretation, and implications and conclusions must be presented to those working in the solid waste industry, regulatory agencies, and policy makers. To achieve these goals, technical papers, articles and tours of the project have been prepared. Two technical papers were published and presented; these papers are discussed below.

The first paper, entitled "Hydraulic Characteristics of Municipal Solid Waste: Findings of the Yolo County Bioreactor Landfill Project", was presented at the 13^{th} International Conference on Solid Waste Technology and Management in Philadelphia, PA, November 1996. This paper provided insight on moisture addition and distribution, and estimated waste permeability.

The second paper was presented at SWANA's 21^{st} Annual Landfill Gas Symposium in Austin, Texas, March 1998. This paper, entitled "Reuse of Shredded Waste Tires for Landfill Gas Collection and Leachate Injection System in Yolo County's Controlled landfill bioreactor Demonstration Project", provided insights on the performance of shredded tires as used for the project. About 375 people in the landfill gas industry both from private industry and public agencies attended the symposium.

In addition to the technical papers, the U.S. Environmental Protection Agency (EPA) Office of Research and Development published a document entitled "Emerging Technologies for the Management and Utilization of Landfill Gas". This document has a section dedicated to the discussion of controlled landfill bioreactors and the Yolo County Project.

Findings of the demonstration project have been presented in seven magazine articles during the grant period. Field tours were conducted for nine different groups from the U.S. EPA, private waste management owners, regulatory agencies and academic institutions.

A web page about the demonstration project is in the final stages and will be posted on Yolo County webpage at http://www.yolocounty.org/ppw. A tri-fold brochure about the project has also been prepared for distribution.

<u>Project Assistance and Support</u>

With the financial assistance of the California Energy Commission (CEC), Sacramento County and the California Integrated Waste Management Board (CIWMB), the construction phase of the project was completed. The CEC provided assistance and support of the project's accelerated methane generation and energy potential. As an owner and operator of a landfill, Sacramento County supported the project's interest in leachate treatment through recirculation. Other benefits of a controlled landfill bioreactor such as accelerated landfill gas generation are also of importance to Sacramento County. The CIWMB provided funds to investigate the use of waste tires as a gas collection medium. John Pacey, former CEO of EMCON Associates, has also provided technical assistance in the design and operation of the project.

The operation and monitoring phase of the project is being carried out with the support of the U.S. DOE, through Public Technology Incorporated's Urban Consortium Energy Task Force (UCETF) and the Western Regional Biomass Energy Program (WRBEP). UCETF provides guidance and review of the project's progress through periodic meetings and correspondence. The WRBEP contract is managed by the Electric Power Research Institute, which provides technical assistance in the project's operation and in analyzing its results.

Partner Don Augenstein, of the Institute for Environmental Management (IEM), has been instrumental to the project's success since it's inception. Mr. Augenstein has provided oversight of the project and technical review of data interpretations, assisted in technical report preparation, and conducted an economic analysis on controlled landfill bioreactors and greenhouse gas abatement costs. Mr. Augenstein brings over 25 years of experience in biomass energy to this project. He has contributed to the white paper on controlled landfill bioreactor, along with John Pacey, to further assist in the commercialization of this technology.

Results

After almost four years of liquid addition and leachate recirculation, results of the project are encouraging. Waste moisture and temperature, leachate flow and composition, landfill gas generation and composition, and landfill settlement were closely monitored throughout this period. Results of these monitoring programs are presented in the following paragraphs.

Waste Moisture and Temperature

Numerous moisture and temperature sensors have provided insight about moisture distribution within the cell, liquid infiltration rates, and landfill decomposition processes. The moisture sensors, along with control valves, enabled control of liquid distribution. Moisture sensor readings also demonstrated that shredded tire infiltration trenches were able to supply uniform moisture delivery without ponding in the trenches. This information allowed better liquid management because infiltration trenches located near the wetter areas could be shut off while infiltration trenches in drier areas were left on to receive more liquid.

Temperature readings provided information on how the liquid addition affected landfill gas generation. The initial wetting front, which used cool groundwater, caused a decrease in waste temperatures in the upper levels near the infiltration trenches, as shown in Figure 2. Temperatures at the lower sections of the cell did not change because as the liquid moved downward it was slowly warmed as a result of anaerobic decomposition processes. With continued liquid addition and leachate recirculation, waste temperatures in the upper levels recovered and the landfill gas generation rate substantially increased.

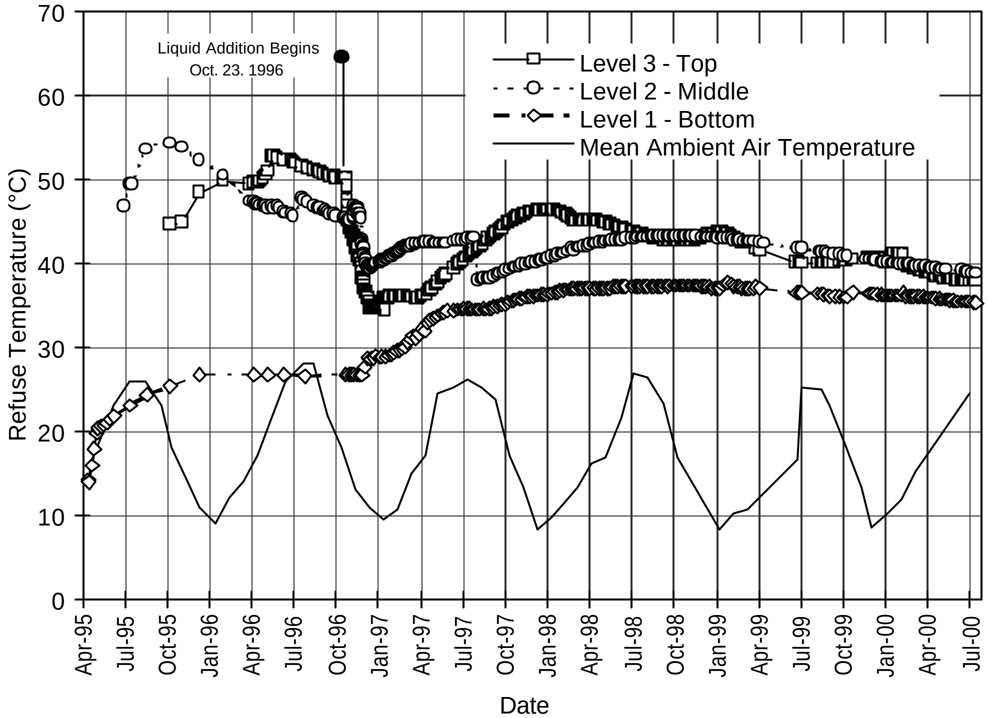

Figure 2. Enhanced cell refuse temperature over time.

Leachate Analysis

Leachate composition for the control and enhanced cells has been monitored throughout the project; the results are discussed below. All leachate analytical results for stated parameters for both the enhanced and control cells are presented in Appendix B. All "none detected" analytical results in the table are presented as the method detection limit, and all "trace" results are presented as the practical quantification limit.

Control Cell Analytical Results

To date, the control cell has not produced a significant volume of leachate. As leachate is generated, it drains into a bucket below the outlet pipe in the control cell manhole. Once an adequate amount of liquid is accumulated, samples are collected for analyses. Table 5 shows the analysis results. Because the control cell leachate flow is low, samples are in equilibrium with the atmosphere before analysis and therefore may not accurately represent the leachate within the cell. Leachate sampled from the control cell is clear, light orange in color and has no distinct odor.

Table 5. Control cell leachate results.

PARAMETER	Units	12/6/96	1/24/97	7/23/97	6/17/98	10/8/98
pH		7.78	8.47	8.05	8.8	9
Chemical Oxygen Demand	mg O/L	98.5	79.9	110	93	91
Total Organic Carbon	mg/L	23	26	39	26	105
Total Kjeldahl Nitrogen	mg/L	45	13.6	26	15	21
Total Alkalinity as $CaCO_3$	mg/L	2420	2370	2250	1800	1,760
Total Dissolved Solids	mg/L	2740	2760	2570	2440	2460
Nitrate as Nitrogen	mg/L	10.4	18	10.9	24	25
Ammonia	mg/L	31	9.6	24	12	16
Magnesium	mg/L	442	451	414	-	-
Potassium	mg/L	94	83	71	-	74
Sulfate	mg/L	1.2	16	1.4	2.5	0
Iron	ug/L	95	83	216	-	-
Manganese	ug/L	208	115	149	-	-

Enhanced Cell Analytical Results

Supplemental liquid addition to the enhanced cell started on October 23, 1996, leachate generation started immediately. Leachate samples were taken throughout the project; select analytical constituent results are shown in Table 6 are discussed below. All results for these parameters are presented in Appendix B.

Table 6. Enhanced cell leachate results.

PARAMETER	Units	11/19/96	12/6/96	1/24/97	7/23/97	6/17/98	10/8/98	2/9/99	5/31/00
pH		7.62	5.75	7.2	7.09	7.3	7.21	7.19	7
Chemical Oxygen Demand	mg O/L	31.9	20,300	5,920	2,770	2,980	3,120	2,650	2,790
Total Organic Carbon	mg/L	9.8	8,930	1,150	850	1,080	1,690	921	844
Total Kjeldahl Nitrogen	mg/L	4	673	518	385	545	564	455	579
Total Alkalinity as $CaCO_3$	mg/L	930	4,590	5,920	4,490	4,270	4,190	4,150	4,450
Total Dissolved Solids	mg/L	1,100	19,800	9,650	6,700	.	7,650	7,250	8,250
Nitrate as N	mg/L	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0
Ammonia	mg/L	3	435	345	320	444	529	422	499
Magnesium	mg/L	154	1,010	758	392	294	-	354	443
Potassium	mg/L	4.9	997	644	224	559	565	517	552
Sulfate	mg/L	7	1,040	6.4	14	0.16	25	42	17
Iron	ug/L	17	152,000	933	199	206	-	731	540
Manganese	ug/L	4,900	41,900	4,000	1,740	1,060	-	946	900

In the early part of November 1996, the leachate generated was light in color with a pH level near neutral, 7.6. On November 27, 1996, the volume of leachate generated nearly doubled while the appearance changed to a black liquid with a strong odor. Analytical results showed a drop in the pH to 5.8 while other constituent levels increased to their peak levels. This drop in pH and the rise of the other constituents indicates the occurrence of the acid phase. By January 24, 1997, the pH rose to neutral, 7.1, while all other constituent levels started to decrease.

Supplemental liquid addition ceased in April 1997 and only generated leachate was recirculated back into the cell. Leachate recirculation continued until December 1998. Cycling the leachate back through the enhanced cell for over two years resulted in a gradual decrease to nearly stabilized low levels for nearly all constituents analyzed. During this period, the pH level has remained stable at around neutral.

Table 7 compares results of the Yolo County Project with typical leachate results from conventional landfills and other recirculation projects (Reinhart and Townsend, 1997). Results shown are a range of magnitudes taken over the various phases of decomposition. In general, the leachate characteristics of the Yolo County Project were consistent with other recirculation projects. Leachate recirculation significantly reduced the peak levels of most constituents analyzed while shortening the time frame for decomposition. Conventional landfill practices result in higher peak levels over a longer decomposition time.

Table 7. Leachate quality comparison over various phases of decomposition.

Constituent	Units	Yolo County	Other Recirculating[1]	Conventional[1]
pH		5.7 - 7.6	5.4 - 8.6	4.7 - 8.8
BOD	mg/L	61 - 5.020	12 - 28.000	20 - 40.000
COD	mg/L	32 - 20.300	20 - 34.560	500 - 60.000
BOD/COD	ratio	0.02 - 0.25	0.05 - 0.98	0.02 - 0.87
Iron	mg/L	.02 - 152	4 - 1.095	20 - 2.100
Ammonia	mg/L	3 - 490	6 - 1,850	30 - 3,000
Chloride	mg/L	93 - 1.400	9 - 1.884	100 - 5.000
Zinc	mg/L	0.03 - 0.20	0.1 - 66	6 - 370

1 Reinhart, D. R., and T. G. Townsend, 1998.

Landfill Gas Analysis

The landfill gas is monitored for flow and composition. As described in the Task section above, gas flow meters measure the flow in each cell separately and the flow is manually recorded several times per week. Additionally, the gas is sampled regularly to determine its composition. Results of the gas generation and composition are provided in Appendix A and are discussed below.

Gas Generation Results

The enhanced cell has generated more than twice as much methane than the control cell. Cumulative methane gas volume for the control and enhanced cell is shown graphically in Figure 3. The cumulative methane volumes for the enhanced and control cells as of June 2000 were 1.32 scf/dry lb and 0.57 scf/dry lb, respectively. As shown in the graph, the methane production of the control cell tapered off in the late spring of 1998 and has since averaged 0.20 scf/min. During the same time period, from July 1998 through June 2000, the enhanced cell continued to produce methane at an average rate of 6.42 scf/min.

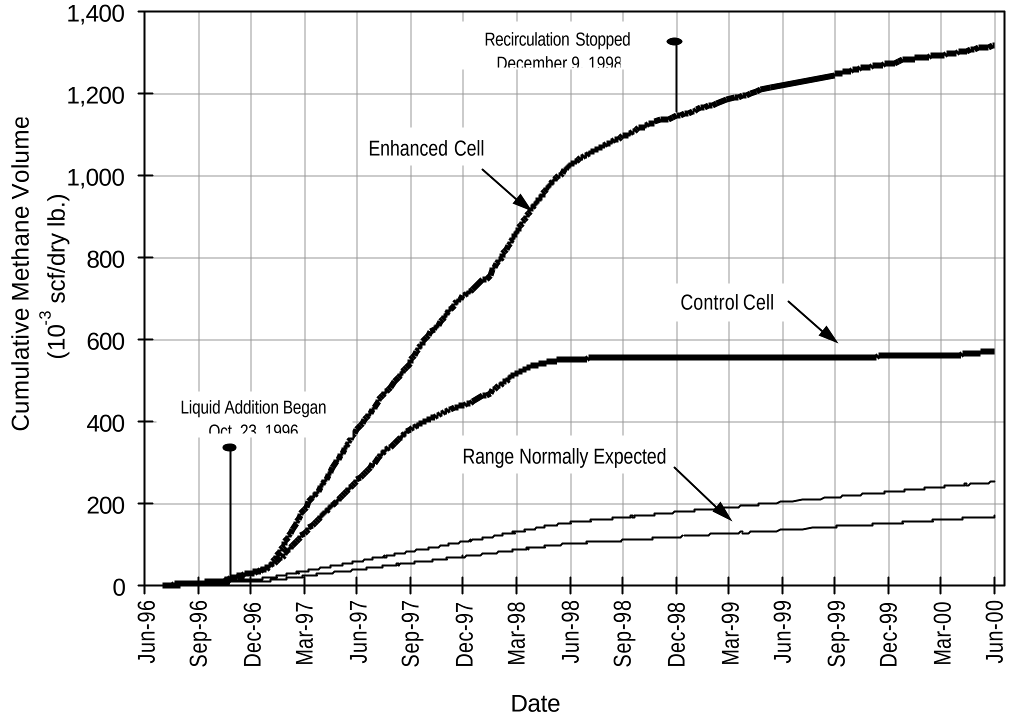

Figure 3. Cumulative methane over time..

The enhanced and control cells methane flow rate is shown in Figure 4. Both cells have followed similar trends in flow rate. Throughout the project, both cells show great fluctuations in readings primarily due to their dependency on barometric pressures and other uncontrollable changes in vacuum flow.

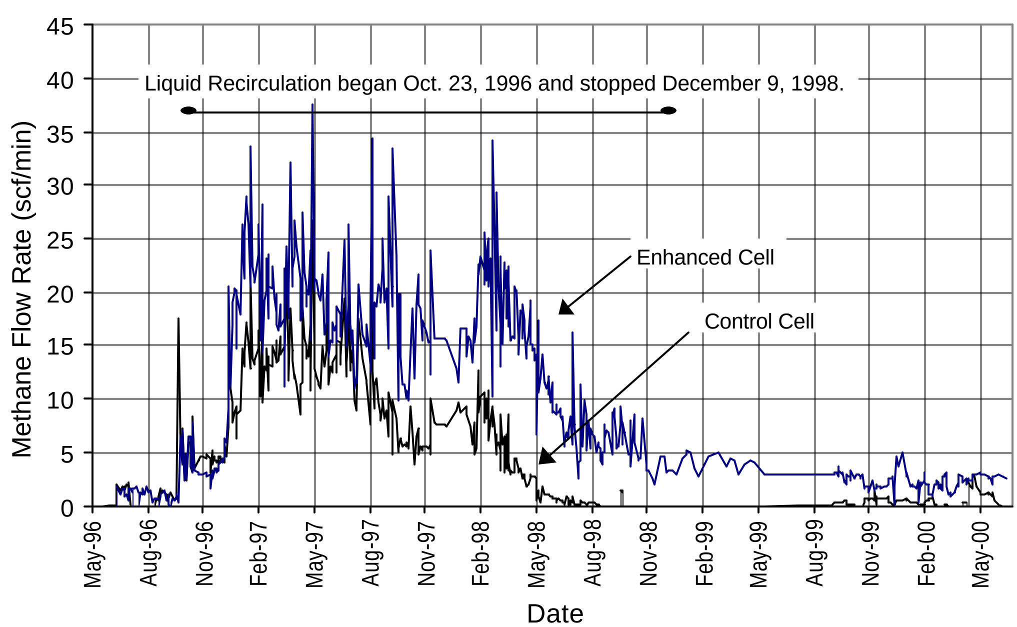

Figure 4. Methane flowrates over time.

Until about 2 months after the start of liquid addition, the flow rate from the two cells closely resembled each other. By the beginning of January 1997, the cells noticeably diverge. The control and enhanced cell seem to follow the same generation trend, however, the enhanced cell always generated more methane after this divergence.

From June to September 1996, the average methane flow rate for the control and enhanced was 0.71 and 1.02 standard cubic feet per minute (scfm), respectively. With the application of vacuum on October 16, the flow rate increased to 4.8 scfm in the control cell and 3.9 scfm in the enhanced cell.

In January 1997, the gas production increased dramatically in both cells. The control cell increased to an around of 5.6 scfm and the enhanced cell increased to 7.0 scfm. No changes in the monitored parameters were observed in the control cell to cause for the increase in the flow rate. However, the increased flow rate in the enhanced cell coincided with recovery of its waste temperature.

Between January 1997 and March 1998, the enhanced cell flow rate averaged 19.1 scfm. In March 1998, the gas production slowly began to decrease until a new average of 6.2 scfm was established between August and November 1998. Recirculation ceased on December 9, 1998 and methane flow rate averaged 2.6 scfm through June 2000.

The control cell averaged 14.2 scfm between January and July 1997. The methane flow rate slowly decreased until the rate was approximately zero by August 1998. A slight increase in flow occurred around September 1999 when the vacuum on the cell began to be managed so as to maintain a negative pressure rather than a certain percent methane. Between September 1999 and June 2000 the control cell averaged 0.1 scfm.

Gas Composition Results

As shown in Figure 5, the methane concentration for both cells started at 42 percent in July 1996. The percentage of methane increased to 52 percent in the enhanced cell and 51 percent in the control cell in August 1996. A vacuum was applied on October 16, 1996. The temporary decrease in methane concentration in late October was a result of repairs being made on the gas collection pipeline (Augenstein et al., 1996).

Between November 1996 and March 1998, the methane concentration fluctuated around 51 percent in the control cell. Beginning in March 1998, the gas composition and generation rate started to decrease in the control cell. By June 1998, the methane concentration decreased to a new average of around 30 percent through March 2000.

The enhanced cell methane content dropped between October and December 1996 corresponding to a decrease in waste temperatures because of the cool liquid infiltrating through the waste and therefore inhibiting bacterial activity. As the waste temperatures slowly recovered and gas generation increased, so did the methane concentration. Between December 1996 and March 2000, the methane concentration fluctuated around 52 percent for the enhanced cell.

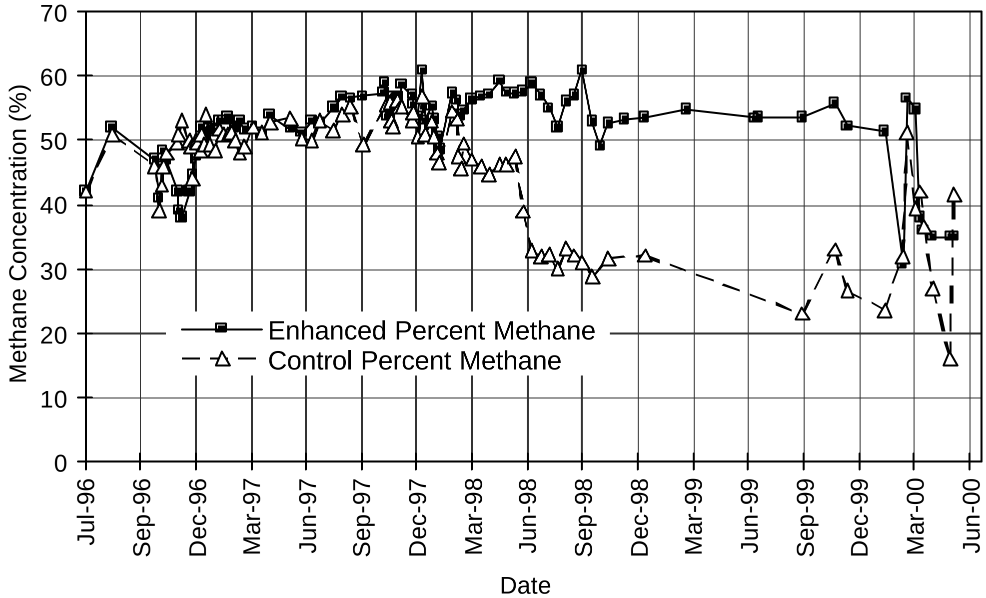

Figure 5. Methane concentrations over time.

Between March and June 2000, the methane content fluctuated greatly in both cells because the vacuum was being managed in a slightly different way. The vacuum was adjusted based on maintaining a negative pressure on the cells, rather than only pulling when there is a significant amount of methane present. The idea was to capture all methane produced and to prevent its escape through any possible leaks in the system. However, the vacuum was also adjusted to prevent oxygen intrusion.

Settlement Analysis

Average settlement results are provided in Appendix C. A graph of the control and enhanced cells average landfill settlement is shown in Figure 6. Based on similar cell performance in landfill gas generation and waste moisture and temperature measurements, the performance of the control and enhanced cell are assumed the same prior to the start of liquid addition. With the start of liquid addition, the enhanced cell settlement rate accelerated dramatically. As of February 2000, the enhanced cell settled more than five times as much as the control cell, averaging 15.54 percent and 2.99 percent respectively.

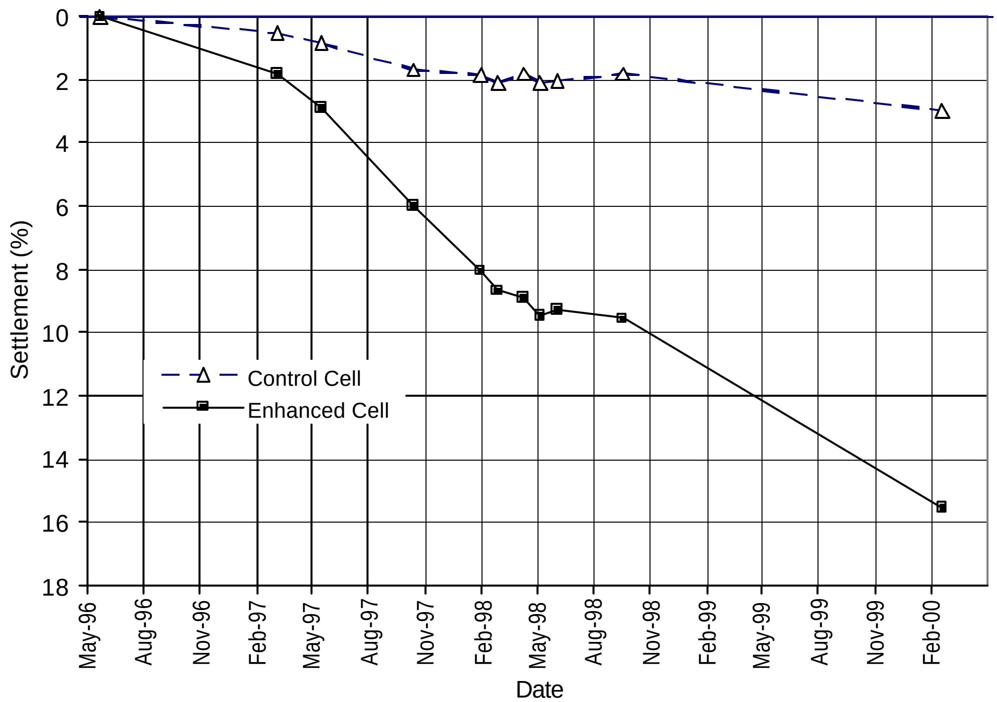

Figure 6. Average settlement for the enhanced and control cells.

In the control cell, the settlement is largest in the center and gradually decreases moving outward to the cell perimeter, which is expected since the total depth of waste decreases at the perimeter. In the enhanced cell, the largest settlement occurred in the southwest corner, near a vertical gas well. Due to the construction of the vertical gas well, the area surrounding the well may have been less compacted than other areas of the cell. Consequently, a preferential pathway may have been created, allowing liquid to move downward more easily in this location. Therefore, the weight increase from the added liquid along with the improved conditions for decomposition may have contributed to the substantial settlement in this area (Moore et al, 1997). The center of the cell showed the next greatest settlement and settlement gradually decreased toward the outward perimeter of the cell.

V. ECONOMIC ANALYSIS

To evaluate controlled bioreactor landfills on a commercial scale, a cost analysis was performed to determine the cost of methane recovery and the value of greenhouse gas abatement. The economic analysis first considers the costs for producing methane-based energy. Then, it considers the costs of greenhouse gas abatement. The greenhouse gas abatement has two components (a) incremental gas emission prevention, and (b) fossil fuel offsets from the utilization of recovered gas.

The fundamental design for all landfills discussed in this analysis, has typical features found in many landfills throughout the U.S. The similarity of design facilitates the comparison of capital and operating costs between conventional and controlled landfills. The controlled bioreactor discussed in this analysis is a hypothetical model that also uses the same fundamental landfill practices, but includes modifications resembling those used in the Yolo County Bioreactor Project.

Economic Accounting Notes

There are various accounting methods that can be used for calculating methane recovery costs and greenhouse gas abatement values. For example, the incremental costs of a controlled landfill bioreactor could be apportioned to energy, greenhouse gas abatement, and/or other waste management benefits. The environmental benefits of methane recovery would also be *credited* towards these same issues. Valuations of potential credits can vary widely.

This analysis attempts to be as conservative as possible in assigning costs. The full cost of a controlled landfill bioreactor is allocated to incremental gas collected. Additionally, to analyze the value of greenhouse cost-effectiveness, the full incremental costs are assigned to greenhouse gas abatement.

To make analysis simpler, all capital expenditures are assumed to occur as a lump sum, one year before the module is completely filled. Although expenditures would actually be spread out over time, this assumption is conservative and introduces little error because most of the necessary expenditure would actually occur later. Likewise, waste placement is assumed to be completed in one year.

For purposes of this analysis, liquid addition starts six months after waste placement is completed and methane generation begins one year after that, which is six months after the start of liquid addition. The *value* of the first full year’s methane generation, for both the controlled landfill and the conventional, is realized two years after completion of waste placement. These times are estimates based on judgment and experience from the Yolo County Project, and can be affected by procedural variations. These times are considered representative of a full-scale operation.

Methane Recovery

There are differences between the ultimate methane recovery and the rate of recovery between a controlled landfill bioreactor and a conventional landfill. The economic assumptions used to describe these differences are discussed in this section.

Methane generation for conventional landfills, either with or without gas controls, is assumed to follow the first-order kinetics model used by the EPA. This standard model was found to be the best fit in a landfill model study by Vogt and Augenstein performed in 1997.

Ultimate methane yield achieved by a controlled landfill bioreactor is 1.8 cubic feet of methane per pound of dry waste, compared to a conventional landfill, which yields 1.4 cubic feet per pound of dry waste. Reasons for this difference are described in the following paragraphs.

For a controlled landfill bioreactor, the landfill gas-capturing efficiency is estimated at 100 percent after placement of the gas collection system and surface liner. Excluding the methane generated during filling, methane generation is assumed to be generated at a constant rate and is complete in five years (Vogt and Augenstein, 1997).

For purposes of this analysis, conventional landfills either with or without gas controls are assumed to have a gas-capturing efficiency of 75 percent, therefore, fugitive emissions are 25 percent. It is also assumed for purposes of calculation that the first full year's recovery is realized at the end of year three and ends 30 years after closure or at the end of year 32, coinciding with the end of 30 year post closure monitoring period as required by federal regulations. After this interval all generated methane is emitted to the atmosphere.

To compare a controlled landfill bioreactor to a landfill *without* gas controls, the incremental operating and maintenance costs of the bioreactor are assumed to accrue at the endpoints of year 2 to year 7. Thereafter they are zero because operating and maintenance costs have been assumed equal as described in the operating costs section. The operating and maintenance costs are assumed as equal for a controlled landfill bioreactor and a landfill *with* gas controls.

The greenhouse potency of methane, relative to CO_2, is 21:1 by weight, meaning methane is 21 more times potent than CO_2. This value is given by the Intergovernmental Panel on Climate Change and the U.S. DOE.

Fundamental Landfill Features

To provide a practical economic comparison, both the conventional landfills and the bioreactor discussed in this economic analysis have several fundamental features in common. These features are average, or typical, of U.S. sanitary landfills. The intent of using these typical features is so that modifications required for a controlled landfill bioreactor could be easily applied at most locations across the U.S.

Design Features

It is assumed that a plastic liner is placed on the surface of each module whether the landfill is operated as convention landfill or as a bioreactor and therefore poses no incremental cost. The plastic liner has become a frequent cover choice at sanitary landfills, which are required to have a cover system with permeability equal to the base liner.

In practice, the module size could range widely, but here it is assumed to be 10 acres further subdivided into four 2.5-acre units using sequential operations. The assumed inflow of 1,000 tons per day amounts to about 1.2 acre-feet per day of compacted waste. Thus, filling a 10-acre module would require 580 days.

The basic landfill design follows Subtitle D regulations, which requires a composite liner consisting of an earth filled layer overlain by a plastic liner, and conventional landfilling practices. Additional important fundamental design features are listed below.

Fundamental Landfill Characteristics

- Waste depth: 60 feet average, plus three feet for cover layers.
- Waste lift depth: 10 feet.
- Module size: ten acres, subdivided into four 2.5 acre units.
- Landfill size and life: 25 modules constructed over 34 years.
- Leachate storage: manhole or surface impoundment reservoir.
- Base liner system: Subtitle D composition.
- Leachate collection and recovery system: capacity as required.
- Surface liner: geomembrane with permeability equal to the base liner system.
- Waste inflow: 1,000 tons per day, time-averaged

Operational Features

A landfill placement rate of 1,000 tons per day was chosen as representative of waste inflow because half of the landfills in the U.S. have an inflow rate of 1,000 tons per day or higher. Although there are many smaller landfills with lower inflow rates, the assumed inflow rate is a reasonable assumption because economics of scale has driven a trend toward fewer and larger regional landfills.

Controlled Landfill Bioreactor Features

The discussion below describes preliminary designs and operational features that will facilitate cost calculations. These designs do not have the degree of completeness needed for implementing an actual project. It is the intent, however, to provide design assumptions with sufficient clarity to allow translation into a detailed design for the full-scale application. The controlled landfill bioreactor used for the economic analysis closely resembles the Yolo County Bioreactor Project.

Design Features

Although it may be convenient to add liquid to waste as it is filled, demonstration results strongly suggest this strategy will lead to rapid methane evolution before gas control mechanisms are ready. To maintain the best methane capturing capacity, this analysis assumes that liquid addition occurs only after waste is filled and covered, therefore, maximizing control of methane generation and capture.

Operational Features

Conventional landfills are filled with waste, lift-by-lift, to the desired design depth. The controlled landfill bioreactor used in this analysis will use chipped greenwaste as daily cover to promote even moisture distribution. The average waste depth for the bioreactor is 60 feet with an approximate density of 1200 pounds per cubic yard (lb/yd^3).

Costs

As discussed previously, both a conventional landfill and a controlled landfill bioreactor incur many of the same costs. In numerous instances, there is an incremental cost difference due to larger size requirements for the bioreactor. However, there are also some costs that are exclusive to the bioreactor.

Some examples of expenses that are incurred for both conventional and controlled landfills include leachate handling costs, gas controls, daily cover, and maintenance. Leachate is generated in either landfill practice. An adequate leachate collection and recovery system is mandated for groundwater protection and must be capable of handling the generated leachate flows. In the Yolo County Project leachate was added to the landfill and percolation rates were easily managed using the same conventional landfill design. Therefore, no incremental costs are assumed for the leachate collection and recovery system.

Daily coverage is also required for sanitary practices. Normal operation and maintenance work is always required. For certain landfills, gas control devices and collection systems may be required under the New Source Performance Standards (NSPS) of the Federal Clean Air Act. Additionally, an impermeable, composite base liner and cover system is also required for groundwater and air quality protection.

Construction Expenses

The majority of landfill construction expenses are inevitably incurred as part of conventional landfill practices and environmental protection. Thus, most costs are independent of whether methane recovery or methane enhancement techniques are used. Additional costs during construction would be incurred due to installing instrumentation and other required equipment; these costs will be accounted for with the instrumentation listed below.

Capital Costs

When using normal design and environmental protection standards, many of the capital costs for a controlled landfill are only incremental due to the increased rate of methane generation. The known capital costs associated with the necessary features of a controlled landfill bioreactor are discussed in the following section and a summary of all the incremental costs is shown in Table 8. These costs are later used to determine gas to energy costs as well as greenhouse cost-effectiveness. However, please note that some items have greater cost uncertainties because of limited available information, and site-specific circumstances.

Table 8. Liquid delivery system components and costs.

#	Item	Installed Cost
1	Main water supply hose	$4,000
2	Supply lines for leachate delivery	$10,000
3	Section headers	$28,000
4	Orifice flow meters on section header inlets	$8,000
5	Pressure gauges	$800
6	Final conduit from header hose to trench	$14,000
7	Protection of terminal end of distribution line	$8,000
8	Pipe fittings	$10,000
9	Filters: Housed stainless wire mesh	$5,000
10	Control Valves	$5,000
11	Inlet flow meters	$7,500
12	QA/QC	$7,500
13	Miscellaneous	$10,000
	SUBTOTAL	**$117,800**
	10% Contingencies	$11,780
	TOTAL COST	**$129,580**

Clearly, a single module should not be assigned the entire cost of any item that serves several modules. Therefore, if the item can be expected to serve all 25 modules, an estimated 4% of the total capital cost of these items is distributed to each module.

Costs of some items will also depend on the scale. For example, increased gas recovery rates will require an increase in the size of gas flares and blowers. In this report, the costs are assumed to rise using a scaled factor.

The estimated cost of equipment includes installation expenses, i.e. fully burdened, with engineering, design, and installation costs considered. Engineering and design costs are low since they will be spread over the assumed 25 modules. All costs are reduced to a per module basis; each module has an area of 10 acres.

Permitting

If design and permitting of a controlled landfill bioreactor were ordinary, there would not be an incremental cost for permitting. However, because this technology is new, permitting review is required, which may mean higher incremental costs. The incremental permitting costs for a controlled landfill bioreactor are estimated to range between $1,000 and $10,000 per module.

Porous Gas Collection Layer

A porous, gas-permeable layer is required beneath the surface geomembrane for gas recovery. Gas migrating towards the surface of the waste passes through the porous layer, which redirects it to a gas collection line. The porous layer is similar to that used in the Yolo County Project which was composed of shredded tires. Shredded tires have performed well as a gas collection medium and have little cost difference from gravel, the material more typically used. The cost per module for the horizontal layer is comparable to the cost of installing five vertical gas collections wells.

Base Layer Gas "Tap" Line

During the filling process, from the start of waste placement to completion of cover and gas collection system, an estimated 3 to 8 percent of the waste's total potential methane could be generated. Therefore, it is beneficial to capture as much of this early methane as possible to limit fugitive emissions. A gas extraction tap line may be installed at base of the module to ensure maximum capture during this critical period. An applied vacuum collects the landfill gas through perforated pipes. The necessary pressure gauge, piping, and valves are estimated to cost $5000 per module.

Landfill Gas Recovery Blower

A gas recovery blower provides the vacuum to extract the landfill gas from the collection well and is also required for proper flare operation. For a landfill without a gas collection system, the total cost of the blower, shared among modules, will be $175,000. The per-module cost is then $7,000. For a conventional landfill with a gas collection system already in place, the increased cost for a larger blower is only $3,200 per module.

Pressure Control Valves

The vacuum applied to the porous horizontal gas collection layer, underlying the surface membrane, must be maintained at a negative vacuum to prevent damage to the membrane and to prevent fugitive surface emissions through liner leaks. Therefore, pressure control valves are necessary to adjust the vacuum, which is dependent on weather conditions. Manual pressure control valves are estimated to be $1000 each. If one is installed in each section the cost would be $4000 per module.

Landfill Gas Collection System

Larger diameter gas collection pipes are necessary to manage the increased gas flow associated with accelerated waste decomposition. For landfills that are already required to install a gas control system, the incremental cost associated with the addition of a controlled landfill bioreactor is $7,000 per module. This is based on an estimated 700 feet of pipe with an incremental cost of $10 per foot. For landfills without a gas collection system, the incremental cost of the pipeline is $50.00 per foot, for a cost of $35,000 per module.

Landfill Gas Flare

Landfills with a gas collection system usually destroy the gas by flaring (burning) it. For landfills that have a landfill gas to energy facility, a landfill gas flare is used as backup to the energy equipment. In either case, a landfill gas flare is a required cost for conventional landfills with gas collection system. An estimated maximum gas flow for a controlled landfill bioreactor is 5,000 cubic feet per minute (cfm). For a landfill without a gas collection system, the total cost of installing a flare is estimated at $875,000. The shared per-module cost will be $35,000. For a conventional landfill that already has a gas collection system, the incremental flare cost is estimated to cost a total of $414,000 or $17,000 per-module.

Credit for Landfill Gas Extraction Wells

When a controlled landfill bioreactor is substituted for the cost of installing a gas collection system as mandated by NSPS regulations, there is a credit for gas well costs avoided. The estimated credit is $4,000 per acre or $40,000 per module.

Landfill Gas Flow Meters

Corrosion resistant gas meters placed at the header pipe of each module provide accurate gas generation measurement. These gas meters provide accurate landfill gas measurements, which helps to evaluate the landfill gas potential remaining in each module. The cost for two meters per module is estimated at $8,000.

Surface Liquid Infiltration Trenches

The controlled landfill bioreactor described in this analysis uses infiltration trenches installed on the surface of each module to allow liquid addition. Each trench is back-filled with shredded tires to promote even moisture distribution. The cost associated with the space occupied by the trenches is negligible since the gate fees collected for tires would cover the landfill space taken. Approximately 40 trenches per acre will provide uniform wetting of the waste. The trenches are estimated to cost $100 each or $40,000 per module.

Liquid Delivery System

In the controlled landfill, liquid must be delivered to the infiltration trenches to enhance methane generation. Essentially, a specialized irrigation system, set up for each module, delivers and distributes a controlled amount of liquid to the infiltration trenches. The thirteen required delivery system components and associated costs are listed and discussed in Appendix E. A summary of the estimated installed cost of all components of the liquid delivery system is shown in Table 9. Contingencies are estimated at 10 percent, for a total cost of $129,580 per module. This represents an average cost of about $13,000 per acre.

Table 9. Maximum estimated incremental costs for a controlled landfill bioreactor compared to conventional landfills.

Item	Compared to a Conventional Landfill Without a Gas Collection System	Compared to a Convention Landfill With a Gas Collection System
Permitting	$10,000	$10,000
Base Layer Gas "tap" Line	$5,000	$5,000
Landfill Gas Recovery Blower	$7,000	$3,200
Pressure control valves	$4,000	$4,000
Landfill Gas Collection System	$35,000	$7,000
Landfill Gas Flare	$35,000	$17,000
Credit for vertical well cost avoided	$0	-$40,000
Landfill Gas Flow Meters	$8,000	$8,000
Surface Liquid Infiltration Trenches	$40,000	$40,000
Liquid Delivery System	$129,580	$129,580
Leachate Surface Impoundment Reservoir	$2,000	$2,000
Liquid Supply Pump for Impoundment	$1,000	$1,000
Moisture, Temperature, and Pressure Sensors	$60,000	$60,000
Datalogger and Remote Access	$15,000	$15,000
Subtotal	**$351,580**	**$261,780**
Contingency at 10%	$35,158	$26,178
TOTAL INCREMENTAL CAPITAL COST	**$386,738**	**$287,958**

Leachate Surface Impoundment Reservoir

In conventional landfills, leachate generated from each landfill module drains through the leachate collection and recovery system to manholes or a larger surface impoundment reservoir. It is then treated on-site or pumped to a publicly owned treatment works for treatment. The total incremental cost of a liquid impoundment reservoir associated with a controlled landfill bioreactor may vary from $0 to $50,000 depending on size and configuration. All modules will share the reservoir, giving a per-module cost of zero to $2,000.

The minimum cost, $0, may arise in various ways. For example, if leachate recirculation is implemented using a staggered sequence. That is, once the first module has reached optimum conditions, the supplemental liquid addition can be applied to the next module. This staged sequence of liquid addition and leachate recirculation allows the landfill to act as a liquid storage reservoir. Therefore, no incremental costs would occur since the reservoir size would stay the same or increase only min imally.

Liquid Supply Pump for Impoundment

Conventional landfills require a pump to transport leachate for onsite or off-site treatment. In a controlled landfill bioreactor, a higher capacity pressure pump is needed to handle liquid distribution. Therefore, the higher capacity pump is only an incremental cost. The added cost is estimated at $25,000 for the landfill, or $1,000 per module.

Moisture, Temperature, and Pressure Sensors

An array of sensors are placed in each module to monitor moisture distribution. The Yolo County Project used a gypsum moisture sensor incased in Plaster-of-Paris. Temperature sensors are used to track any sudden changes and overall decomposition conditions. Pressure sensors are placed at the bottom of the cell to measure head over the liner, allowing maximum monitoring control over water input and output. On average, four of each sensor type should be placed per acre for a total of 120 sensors per module. The estimated installed cost, including instrumentation leads at $500 each, is $60,000 per module.

Datalogger and Remote Access

A datalogger is connected to the moisture sensors to allow continuous measurement. A remote telemetry unit (RTU) will allow remote access to the data from an office. The cost of the datalogger and RTU is estimated at $15,000 per module, which is 4 percent of the $375,000 total.

Operational Costs

In addition to capital costs there will be operating costs associated with a controlled landfill bioreactor. The operating costs are estimated based on the demonstration project experience. The system would ordinarily function with limited staffing. The exact amount required depends on the existing operation.

For a conventional landfill *without* a gas collection system, staffing is estimated to cost approximately 20 percent of a fully burdened person per year or $20,000, and about five percent of the capital for another $20,000 per year for maintenance. So, the total cost is estimated at $40,000 per year.

However, for a conventional landfill *with* a gas collection system, there will also be costs for personnel and capital expenses for maintenance and weekly operational adjustments. Moreover, the gas-extraction maintenance period for a controlled landfill bioreactor should be under 10 years, compared to the *at least* 30 years that is mandated for conventional landfills. Therefore, *over time,* for the purposes of this analysis, the costs associated with the maintenance and operation of the gas system are assumed as equal between the two practices. Therefore the costs of a controlled landfill bioreactor are considered to be the sum of capital costs as shown in Table 9.

Cost Comparison

The following analysis first compares the cost of a controlled landfill bioreactor to a conventional landfill *with* a gas collection system and then compares it to one *without* a gas collection system. The landfills are evaluated on methane recovery and greenhouse gas emissions. Greenhouse gas emissions are expressed as carbon dioxide (CO_2) equivalents. Representative discount rates are used to calculate the CO_2 equivalent abatement cost. Greenhouse cost effectiveness will be expressed in terms of dollars per metric ton (tonne) and annual tonnes of equivalent carbon dioxide (CO_2) abated for the US. The methane energy production and methane abatement costs are calculated for each case.

Controlled Landfill Bioreactor Vs. Conventional Landfill

This economic evaluation compares a controlled landfill bioreactor to a conventional landfill both with and without gas controls. To begin, the terms and timing used for the economic analysis are described.

Four percent of total methane potential is initially recovered by a tap-line gas extraction system at the bottom of the cell. Its value is realized at the end of year 2, one year after completion of waste placement. Recovery continues for five years to the end of recovery at t = 7 years after capital expenditure (6 years after filling is complete).

The starting point for operating costs is one year after filling is complete. Incremental labor during earlier construction was already included in the capital costs. Operating cost terms are summarized in Table 10 and detailed calculations in Appendix D.

Table 10. Present worth of a landfilled bioreactor operating costs at given discount rates.

Discount Rates	0%	7%	15%
Present Worth	$240,000	$174,467	$120,002

To provide a range of economic perspectives, the analysis uses three discount rates (implied costs of funds in annual percentage rates) of 0, 7, and 15 percent (d = 0, 7, 15). By using the present worth of controlled landfill bioreactors and the discounted methane recovery outlined in Appendix D, the calculated mean gas costs are shown in Table 11.

Table 11. Mean methane costs of a landfill bioreactor compared to conventional landfills.

Landfill Type	Discount Rate 0% APR	Discount Rate 7% APR	Discount Rate 15% APR
Without Gas Controls	$0.318/MCF	$0.454/MCF	$0.695/MCF
With Gas Controls	$0.393/MCF	$0.419/MCF	$0.575/MCF

The calculated gas cost could range widely because component costs, discussed above, may range widely. For example, costs that could vary by twofold or more include water supply piping or permitting. In addition to the obvious uncertainties in these areas, there are other cost unknowns. There are also uncertainties in generation kinetics, gas yield, and presumed recovery efficiency. The best available information and judgement has been used, but remaining unknowns add to uncertainties.

Greenhouse Emission Comparison

The greenhouse emission evaluation again compares a controlled landfill bioreactor to conventional landfills, one with and one without gas controls. Factors evaluated for this comparison are methane emissions and fossil fuel offsets. Costs per unit of greenhouse gas abated are calculated and expressed as CO_2 equivalents.

For convenience in the following calculations, time scales and nomenclatures are kept the same as in the earlier cases where methane cost was calculated. Thus, filling is complete at the end of year 1. Methane generation by the conventional landfill is assumed to follow the first-order kinetics.

Greenhouse Economic Analysis

The economic analysis of greenhouse cost-effectiveness of landfill gas control performed here is a variant of a discounted cash flow, or discounted value analysis, applied to prevention of emissions as they would occur over time. It can be commented that “discounted cash flow” does not seem ideal for terminology here, since results are emissions abatement and their worth is those units for abatement, discounted into the future. However, a discounted cash flow analysis is very widely accepted and will be used below.

Depending on the perspective, a range of discount rates can be used. A case can be made for taking full early credit for prevented landfill greenhouse gas emission. In this case, the discount rate is simply zero. An argument for including a discount rate of zero is that an environmental technology, by definition, must protect and value the future. The future should not be discounted to the extent usually used for investment. From policy standpoints, there is advocacy for dealing with future atmospheric greenhouse methane rises through early actions. A low discount rate is also supported on the basis that methane capture, once assured, is future environmental benefit in the bank. As such, it could deserve credit as of the time of assurance of environmental benefit.

In the following analyses, energy is expressed in the terms used by the U.S. gas industry; one MCF is equal to 1,000 cubic feet of methane or 10^6 Btu. Energy recovered will have units of MCF. Emissions will have units of CO_2 equivalents abated and the units are metric tons (tonnes) CO_2. Energy, or abatement of methane emission (CO_2 emission offsets) at some future time will have a value or "worth". For example, at a carbon tax of $27 per tonne, abatement of methane emissions could be "worth" $10 per tonne CO_2 equivalent.

The discount rate, though applied to energy or emissions, also has monetary meaning being equivalent to the cost of capital, interest cost on funds, or necessary gross return. For this analysis, discount rates of zero, 7, 15 percent are used. Pollution abatement and other environmental benefit projects are characterized by low costs of funds. Further assumptions used in cost-effectiveness calculations are described below.

The Intergovernmental Panel on Climate Change value for greenhouse methane equivalence is used, in which methane’s potency is 21 times its weight of CO_2. At this potency, one MCF of methane equates to 0.4 metric tonnes of CO_2 in greenhouse terms. Using this CO_2 equivalent of methane, both the conventional landfills, with and without gas controls, generate a total of 560,000 tonnes of CO_2 equivalents.

Similar to the time convention previously described, four percent of the greenhouse gas emissions from the controlled landfill bioreactor and the conventional landfill with gas controls are assumed to accrue at the end of year 2. Thereafter, the controlled landfill bioreactor emissions are negligible. Between years 3 and 32, the conventional landfill with gas controls emits 25 percent of greenhouse gas generated. After 32 years, all generated greenhouse gas is emitted to the atmosphere.

For controlled landfill bioreactors and conventional landfills with gas controls, 92 percent of gas generation occurs after three years. The CO_2 equivalent emission for the conventional landfill without gas controls is 44,800 tonnes at year 2. The CO_2 equivalent emissions of the landfill with gas controls and the controlled landfill bioreactor are 22,400 tonnes at year 2. For the landfill with gas controls, the CO_2 equivalent emission is 25 percent of 22,400 tonnes from years 3 to 32. Thereafter, all generated methane is emitted.

For the conventional landfill with gas controls and the controlled landfill bioreactor, it is assumed that 80 percent of methane is used in an energy application. This energy application is assumed to be electricity generation. Electricity generation by methane has an efficiency of 0.1 megawatt per thousand cubic feet of methane (MWh/MCF). These numbers can vary but are representative. Methane used for electrical energy displaces other fuels, which emit 0.9 tonnes CO_2/MCF. Thus, the captured methane provides a further CO_2 offset at 80 percent use of 0.072 tonnes CO_2/MCF.

For both the conventional and the controlled landfill bioreactor, it is assumed that filling is completed in a 500-day interval that remains relatively dry. During this time, methane generation is limited to volumes equal to the conventional landfill. Thereafter, the methane is generated and captured at 337,600 MCF/year, with value accruing at ends of years three through seven inclusive.

The CO_2 found in landfill gas cannot be considered a net greenhouse gas addition since it represents atmospheric CO_2 captured in the first place. Landfills sequester carbon. The total equivalent fossil CO_2 abatement, both from fossil CO_2 displacement and greenhouse gas emission reduction is shown in Table 12. Appendix D details the discounted value analysis of CO_2 offsets and CO_2 emissions for each case. This is actually a "debit" analysis since emissions have a negative value. "Present value" is the discounted emission, in units of tonnes CO_2.

Table 12. Total equivalent fossil CO_2 abatement and cost.

Landfill Bioreactor versus	**Landfill without gas controls**			**Landfill with gas controls**		
Discount Rate	0%	7%	15%	0%	7%	15%
Fossil CO_2 Offsets	125,568	90,979	62,594	60,502	59,422	45,775
CO_2 Equivalent Emission Abatement	528,151	227,023	117,749	127,947	52,443	25,930
Total CO_2 Equivalent Greenhouse Benefit (tonnes)	653,719	318,002	180,343	188,449	111,865	71,705
Capital Cost Differential to Attain Benefit	$386,738	$386,738	$386,738	$287,958	$287,958	$287,958
Operating Expense, discounted	$240,000	$174,467	$120,000	$0	$0	$0
Total	$626,738	$561,205	$506,738	$287,958	$287,958	$287,958
Cost per Tonne CO_2	**$0.96**	**$1.76**	**$2.81**	**$1.53**	**$2.57**	**$4.02**

It is important to recognize that the calculated costs are conservative because all incremental costs were assigned to greenhouse gas reduction. No credit or revenue was taken for methane energy recovery or any other waste management benefit. Any such credit assigned to other benefits could significantly reduce net cost of greenhouse gas abatement.

Economic Conclusions

The costs of a controlled landfill bioreactor for CO_2 abatement or renewable energy appear attractive by most extant standards. The costs for greenhouse gas abatement are agreeable even when all incremental costs of a controlled landfill bioreactor are assigned to abatement. Alternatively, if all incremental costs are assigned to incremental recovered methane, the costs of recovered methane are reasonable. This is true whether comparing a controlled landfill bioreactor to a conventional landfill without methane controls, or conventional landfills with gas controls as mandated under law.

A CO_2 equivalent abatement cost of $1 to $5 per tonne equates to a cost of $3 to $14 per tonne carbon. Such cost is still an order of magnitude below the costs estimated for other CO_2 carbon reductions necessary to meet specified targets that were recently estimated by the U.S. DOE's Energy Information Administration (U.S. DOE, 1998). The calculated methane costs of $0.50/ MCF (Table 11) are about half the cost of natural gas.

Clearly, the calculated cost of methane abatement could vary with many factors. For example, preceding assumptions for the conventional landfills with gas controls can be shown to result in fugitive emissions, which are about 35 percent of total generation. If fugitive emissions for the landfill with gas controls were to be halved by operational modifications, the incremental cost of abatement by a controlled landfill bioreactor would approximately double. For the conventional landfill without gas controls, the cost of carbon abatement would rise from $3 to $14 per tonne to $6 to $28 per tonne.

VI. SUMMARY

The benefits of a controlled landfill bioreactor are considerable and include leachate treatment, landfill life extension, reduced greenhouse gas emissions, shorter stabilization periods and green energy feasibility. The Yolo County project has been successful in providing evidence of the numerous benefits. This project has also been successful in providing the framework for advancement to large-scale designs. Monitoring and analysis will continue for this project to provide further evidence of long term benefits.

VII. REFERENCES

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VIII. APPENDICES

A. GAS PRODUCTION DETAILS
B. LEACHATE SAMPLING PARAMETERS
C. AVERAGE CELL SETTLEMENT
D. COST ANALYSIS
E. LIQUID DISTRIBUTION SYSTEM
F. CONTACTS

Gas Production Details

Date	Landfill Gas Volume (100 ft³) Control	Enhanced	Methane Content (%) Control	Enhanced	Methane Gas Flowrate (standard ft³/min) Control	Enhanced	Cumulative Methane Volume Per Pound of Dry Waste 10^{-3} (scf/dry lb) Control	Enhanced
6/12/96	92	9	0.42	0.42	0.00	0.00	0.0	0.0
7/2/96	154	13			0.10	0.01	0.2	0.0
7/3/96	186	42			2.05	1.88	0.3	0.1
7/11/96	574	322			1.50	1.10	1.6	1.1
7/12/96	632.5	369.1			1.87	1.52	1.8	1.2
7/16/96	832.1	542.8			1.65	1.45	2.4	1.8
7/17/96	893	596			1.89	1.67	2.6	2.0
7/18/96	940.2	622.1			1.42	0.79	2.8	2.1
7/19/96	994.4	654			1.92	1.14	3.0	2.2
7/22/96	1166.2	696.1			1.83	0.45	3.5	2.3
7/23/96	1213.9	726.6			1.27	0.82	3.7	2.4
7/24/96	1269	765.8			2.11	1.52	3.9	2.6
7/25/96	1271.3	821.4			0.07	1.62	3.9	2.8
7/26/96	1271.3	863.1			0.00	1.54	3.9	2.9
7/29/96	1271.3	982.2			0.00	1.26	3.9	3.3
7/30/96	1271.3	982.2			0.00	0.00	3.9	3.3
7/31/96	1271.3	1032.9			0.00	1.57	3.9	3.5
8/2/96	1271.3	1128.8			0.00	1.63	3.9	3.8
8/6/96	1271.3	1347.8			0.00	1.77	3.9	4.5
8/7/96	1271.3	1390.9			0.00	1.20	3.9	4.7
8/8/96	1271.3	1429			0.00	1.28	3.9	4.8
8/9/96	1271.3	1429			0.00	0.00	3.9	4.8
8/13/96	1271.3	1571			0.00	1.16	3.9	5.3
8/14/96	1271.4	1605.9			0.00	0.98	3.9	5.4
8/15/96	1271.4	1644	0.51	0.52	0.00	1.19	3.9	5.6
8/16/96	1271.4	1683.3			0.00	1.57	3.9	5.7
8/19/96	1271.4	1775.7			0.00	1.05	3.9	6.0
8/20/96	1271.4	1828.5			0.00	1.81	3.9	6.2
8/26/96	1271.4	2045			0.00	1.20	3.9	7.0
8/27/96	1271.4	2090			0.00	1.38	3.9	7.2
8/30/96	1271.4	2124.5			0.00	0.40	3.9	7.3
9/4/96	1271.4	2226.5			0.00	0.68	3.9	7.6
9/6/96	1309.6	2268.2			0.63	0.67	4.0	7.8
9/9/96	1352.8	2333.1			0.48	0.71	4.2	8.0
9/10/96	1380.5	2333.2			0.87	0.00	4.3	8.0
9/12/96	1465.8	2377.6			1.59	0.81	4.6	8.2
9/13/96	1511.8	2417.7			1.33	1.14	4.7	8.3
9/16/96	1609.8	2522.8			1.16	1.22	5.1	8.7
9/17/96	1653.6	2562.5			1.43	1.27	5.2	8.9
9/19/96	1724.8	2641.6			1.26	1.38	5.4	9.1
9/23/96	1850.8	2699.6			1.07	0.48	5.9	9.3
9/25/96	1873	2732			0.37	0.53	6.0	9.5
9/26/96	1898.1	2768.4			0.79	1.12	6.0	9.6
9/27/96	1917.2	2769			0.66	0.02	6.1	9.6
9/30/96	2018.7	2769			1.19	0.00	6.5	9.6
10/3/96	2092.5	2822			0.83	0.59	6.7	9.8
10/7/96	2159.4	2881.5			0.57	0.50	6.9	10.0
10/8/96	2177.6	2904.2			0.67	0.82	7.0	10.1
10/10/96	2235.1	2964.1			0.96	0.98	7.2	10.3
10/11/96	2769.5	2973.4			17.60	0.30	9.0	10.3
10/15/96	3479.1	3747.7			6.08	6.50	11.5	13.1

Gas Production Details

Date	Landfill Gas Volume ($100\ ft^3$)		Methane Content (%)		Methane Gas Flowrate (standard ft^3/min)		Cumulative Methane Volume Per Pound of Dry Waste 10^{-3} (scf/dry lb)	
	Control	Enhanced	Control	Enhanced	Control	Enhanced	Control	Enhanced
10/17/96	3706	3982			3.80	3.84	12.3	13.9
10/18/96	3900.7	4179.1			7.17	7.11	12.9	14.6
10/21/96	4166.7	4403.8			2.93	2.42	13.8	15.4
10/22/96	4255.2	4498.6			3.35	3.52	14.1	15.8
10/23/96	4396.4	4650.9			4.48	4.74	14.6	16.3
10/24/96	4540.5	4805.6	0.46	0.47	4.27	4.75	15.1	16.8
10/25/96	4621	4893			2.32	2.61	15.3	17.1
10/28/96	5232.4	5527.2			5.98	6.42	17.2	19.1
10/31/96	5852.1	6179.7	0.39	0.41	5.86	6.55	19.0	21.2
11/1/96	5969.7	6301.1			3.59	3.94	19.3	21.5
11/4/96	6311	6618			3.11	3.06	20.3	22.5
11/5/96	6453.4	6740.4	0.43	0.46	8.43	7.75	20.7	23.0
11/8/96	6823.6	7072.3	0.46	0.49	3.44	3.25	22.0	24.1
11/12/96	7347.5	7498.7	0.48	0.47	4.19	3.09	23.8	25.5
11/14/96	7580.9	7676.1			4.33	2.99	24.6	26.0
11/15/96	7718.9	7770.5			4.56	2.83	25.1	26.4
11/20/96	8390.3	8249.6			4.54	2.94	27.4	27.9
11/21/96	8531.1	8345.9			4.59	2.85	27.9	28.2
11/25/96	9047.7	8740.1			4.43	3.07	29.7	29.5
11/27/96	9331.6	8933.8	0.50	0.42	4.77	2.73	30.7	30.0
12/2/96	9952.1	9488.3	0.51	0.39	4.49	2.97	33.0	31.6
12/4/96	10121.9	9613.6			3.01	1.65	33.6	31.9
12/5/96	10277.4	9746.2			5.22	3.30	34.2	32.3
12/6/96	10385.3	9842	0.53	0.38	3.79	2.61	34.6	32.6
12/10/96	10888.6	10314.7			4.56	3.32	36.4	33.9
12/11/96	11004.7	10434.5			4.33	3.47	36.9	34.3
12/12/96	11132.6	10570			4.29	3.53	37.3	34.7
12/13/96	11249	10687			3.96	3.09	37.7	35.0
12/16/96	11575.1	11038.9			4.05	3.40	38.9	36.0
12/17/96	11706.1	11179.9			4.64	3.88	39.4	36.4
12/18/96	11834.6	11325.2			4.54	3.99	39.9	36.9
12/19/96	11968.1	11476.2	0.50	0.42	4.49	4.26	40.4	37.3
12/23/96	12493.1	12042.7	0.49	0.42	4.33	4.00	42.1	39.1
12/24/96	12608.3	12165.9	0.44	0.45	4.25	4.45	42.5	39.5
12/26/96	12863.2	12447.9			4.06	4.40	43.3	40.4
12/27/96	13055.3	12664.2			5.79	6.38	44.0	41.2
12/30/96	13472.9	13210.2			4.63	5.92	45.4	43.0
12/31/96	13715.4	13525.8	0.50	0.48	7.33	9.06	46.2	44.1
1/2/97	14631.8	14560.4	0.50	0.49	18.16	20.55	49.4	47.7
1/3/97	15037.5	14971.1			11.07	11.23	50.8	49.2
1/6/97	15935.1	16555.9			9.59	16.96	53.9	54.8
1/7/97	16156	17075.5	0.49	0.50	7.79	19.11	54.7	56.7
1/9/97	16657.4	18227.3	0.51	0.52	8.70	20.05	56.5	61.1
1/10/97	16867.3	18717.3			8.67	20.30	57.3	62.9
1/13/97	17624.5	20401.8	0.54	0.52	9.37	20.23	60.0	69.1
1/14/97	17812.1	20839.9	0.49	0.51	6.32	14.69	60.7	70.7
1/15/97	18033.9	21359.8			8.49	19.80	61.5	72.6
1/21/97	19528.9	24471.9	0.54	0.51	8.98	17.91	66.9	84.2
1/23/97	20359.9	25868.2	0.49	0.52	14.78	26.25	69.8	89.4
1/24/97	20786.1	26562.6			14.22	24.48	71.2	92.0

Gas Production Details

Date	Landfill Gas Volume (100 ft^3)		Methane Content (%)		Methane Gas Flowrate (standard ft^3/min)		Cumulative Methane Volume Per Pound of Dry Waste 10^{-3} (scf/dry lb)	
	Control	Enhanced	Control	Enhanced	Control	Enhanced	Control	Enhanced
1/27/97	21960.8	28383.8			13.00	21.31	75.3	98.7
1/28/97	22389.1	29105.8			14.34	25.54	76.8	101.4
1/29/97	22911.8	29944			17.12	29.01	78.6	104.6
1/30/97	23401.1	30726.5	0.48	0.52	16.97	28.33	80.3	107.5
2/3/97	25237.1	33726.4			15.38	26.23	86.8	118.9
2/5/97	25945	34819.3			12.78	20.59	89.3	123.0
2/6/97	26330.2	35433.2			12.88	21.41	90.9	125.7
2/7/97	26658.1	35941.7	0.52	0.53	21.06	33.65	92.8	128.7
2/10/97	27804.8	37739.6			13.84	22.36	97.0	135.6
2/11/97	28243.4	38421.6			13.28	21.26	98.6	138.2
2/12/97	28555	38879.5	0.51	0.53	13.59	20.85	99.7	140.0
2/18/97	31087.5	42736.5			14.79	23.51	108.9	154.8
2/19/97	31433.5	43269			16.36	26.29	110.6	157.6
2/20/97	31721.5	43721.1			10.39	17.03	111.8	159.6
2/21/97	31991.8	44109.8	0.51	0.54	10.20	15.45	112.7	161.1
2/24/97	33354	46203			17.45	28.26	118.0	169.8
2/25/97	33624.3	46616.7			14.59	23.53	119.4	172.2
2/26/97	33915	47015.9	0.51	0.53	9.72	14.26	120.5	173.7
2/27/97	34327.1	47588.9			12.99	19.30	121.9	175.9
3/3/97	35825.9	49816.9			12.73	20.22	127.1	184.3
3/4/97	36196.8	50364.7			14.66	23.14	128.7	186.9
3/5/97	36451.2	50749	0.50	0.52	10.70	17.52	129.8	188.7
3/6/97	36908.6	51464.7			13.89	23.56	131.4	191.4
3/7/97	37232.9	51926.2			13.29	20.50	132.5	193.1
3/12/97	39189.1	54738.1			13.05	20.35	139.2	203.8
3/13/97	39649.8	55389.3	0.49	0.53	14.82	22.37	140.8	206.3
3/18/97	41775.4	58095.8			14.29	19.43	148.1	216.4
3/19/97	42179.5	58597.7			13.67	18.12	149.5	218.3
3/20/97	42619.1	59143.5	0.49	0.52	15.49	19.74	151.1	220.4
3/21/97	43006.5	59622.7			13.37	16.97	152.4	222.1
3/24/97	44249.6	61078.9			13.58	16.33	156.9	227.6
3/25/97	44667.4	61565.8			15.78	18.88	158.4	229.4
3/27/97	45491.1	62512.3			14.21	16.76	161.3	232.9
3/31/97	47183.9	64453.2			14.96	17.61	167.3	240.2
4/1/97	47516.8	64769.3			11.45	11.16	168.5	241.4
4/2/97	47965	65242.3			20.50	22.21	170.7	243.7
4/3/97	48417.9	65730.9			14.20	15.73	172.3	245.5
4/4/97	49013.6	66413.5	0.52	0.52	21.01	24.27	174.4	248.1
4/7/97	50138.1	67774.5			14.32	17.48	178.8	253.6
4/8/97	50486.3	68343.9			11.71	19.30	180.1	255.7
4/9/97	50828.3	68900.9			11.98	19.67	181.3	257.8
4/10/97	51338.6	69784.5			18.38	32.09	183.2	261.0
4/14/97	52974.8	72051.5			14.62	20.42	189.1	269.4
4/15/97	53419.6	72712.7			14.62	21.90	190.7	271.9
4/16/97	53761.7	73272.9			13.50	22.29	191.9	274.0
4/17/97	54103.6	73935.2			11.94	23.32	193.2	276.4
4/18/97	54445.6	74666.5	0.51	0.51	12.28	26.73	194.4	279.2
4/21/97	55431.6	76727			11.43	24.30	198.0	287.0
4/28/97	57110.1	80871.2			8.50	21.35	204.1	302.7
4/29/97	57423.9	81339.5			11.37	17.28	205.3	304.4

Gas Production Details

Date	Landfill Gas Volume ($100\ ft^3$)		Methane Content (%)		Methane Gas Flowrate (standard ft^3/min)		Cumulative Methane Volume Per Pound of Dry Waste 10^{-3} (scf/dry lb)	
	Control	Enhanced	Control	Enhanced	Control	Enhanced	Control	Enhanced
4/30/97	57759	81840.9			11.59	17.66	206.5	306.3
5/1/97	58171.1	82449.2			11.84	17.78	208.0	308.6
5/2/97	58500.8	82916.8	0.53	0.54	18.72	27.55	209.4	310.8
5/5/97	59841.5	84729.5			15.59	21.87	214.3	317.7
5/6/97	60264.6	85293.5			14.85	20.53	215.8	319.9
5/7/97	60661.9	85812.2			13.75	18.63	217.2	321.8
5/8/97	61065.2	86351.7			14.66	20.35	218.7	323.9
5/12/97	62676.1	88546.7			13.93	19.69	224.5	332.3
5/13/97	63159.2	89201.7			16.95	23.85	226.2	334.8
5/14/97	63463.9	89625.8			10.69	15.44	227.4	336.4
5/15/97	63784.2	90079.3			11.73	17.23	228.5	338.2
5/16/97	64280.1	90752.5			26.66	37.55	231.2	342.1
5/19/97	65559.5	92418.2			14.97	20.22	235.8	348.4
5/20/97	66017.2	93124.4			15.73	25.19	237.5	351.1
5/21/97	66430	93780.9			12.84	21.18	239.0	353.6
5/22/97	66722	94269.5			12.15	21.08	240.1	355.6
5/27/97	68375	97024.3			11.52	19.92	246.0	366.1
5/28/97	68687.2	97546.3			11.39	19.76	247.2	368.1
5/29/97	69008.4	98086.9			11.00	19.22	248.3	370.2
6/2/97	70551.7	100262.5			14.86	21.73	254.5	379.3
6/4/97	71266.6	101106.9	0.53	0.52	13.04	16.09	257.2	382.7
6/9/97	73470.6	103591.6			14.52	17.10	264.8	391.8
6/10/97	73899.5	104079.3			16.22	19.27	266.2	393.6
6/11/97	74371.2	104609.9			20.14	23.67	268.3	396.1
6/12/97	74807.3	105119.3			11.41	13.93	269.7	397.9
6/16/97	76428.6	106984			12.95	15.56	275.1	404.5
6/17/97	76715.1	107322.6			12.40	15.31	276.1	405.6
6/19/97	77445.6	108211.7			13.48	17.14	278.9	409.3
6/23/97	79341.5	110316.7	0.50	0.51	13.70	16.40	284.6	416.3
6/24/97	79931.9	110972.7			14.11	16.89	286.4	418.5
6/25/97	80249.8	111333.4			12.56	15.37	287.6	420.0
6/26/97	80688.5	111822.8			15.52	18.67	289.0	421.7
7/1/97	83181.6	114524.9			15.32	17.90	296.9	431.2
7/2/97	83568.3	114961			13.19	16.03	298.1	432.6
7/3/97	84004.1	115419.3			13.91	15.77	299.5	434.2
7/9/97	87998.3	119954	0.50	0.53	19.32	24.78	311.8	450.3
7/10/97	88432.8	120432.3			12.05	14.99	313.1	452.0
7/11/97	88881.5	120884.7			13.35	15.21	314.5	453.6
7/14/97	90486.8	122559.2			16.00	18.85	319.4	459.5
7/15/97	91010.1	123134.4			21.23	26.36	321.1	461.6
7/16/97	91590.8	123776.9			12.67	15.84	322.8	463.8
7/17/97	91902	124093.1			13.58	15.59	323.8	465.0
7/18/97	92387.6	124584.2			14.60	16.68	325.3	466.7
7/21/97	93726.8	125881.9			13.42	14.69	329.4	471.3
7/22/97	94317.5	126444.4			15.25	16.41	331.2	473.3
7/23/97	94615.4	126737.2	0.53	0.53	9.80	10.97	332.2	474.4
7/28/97	95957.8	128337.2			8.87	12.05	336.7	480.6
7/29/97	96258	128659.4			9.44	11.54	337.7	481.8
7/30/97	96834	129261.2			17.46	20.79	339.6	484.2
8/6/97	99923	132418.3			13.77	16.03	349.9	496.4

Gas Production Details

Date	Landfill Gas Volume ($100\ ft^3$)		Methane Content (%)		Methane Gas Flowrate (standard ft^3/min)		Cumulative Methane Volume Per Pound of Dry Waste 10^{-3} (scf/dry lb)	
	Control	Enhanced	Control	Enhanced	Control	Enhanced	Control	Enhanced
8/13/97	102459.5	135247.7			11.78	14.97	358.3	507.3
8/14/97	102735.5	135588.6	0.52	0.55	11.57	17.04	359.2	508.7
8/18/97	103751.8	137069.5			7.63	13.25	362.6	514.6
8/19/97	103994.3	137319.8			10.14	12.47	363.4	515.7
8/20/97	104427.2	137850.9			12.88	18.84	364.8	517.8
8/21/97	104928.1	138520.5			21.58	34.40	367.4	521.9
8/22/97	104962.5	138566.8			12.61	18.59	368.2	523.2
8/25/97	105666.8	139456.2			9.11	13.72	370.9	527.3
8/26/97	106029.2	139882.9			11.37	15.96	372.1	529.0
8/27/97	106420.2	140433.2			11.36	19.06	373.4	531.2
8/28/97	106787.8	140921.3	0.54	0.57	11.88	18.66	374.6	533.2
9/2/97	108247.3	143579.6			9.62	20.71	379.5	544.0
9/3/97	108438.8	143958			8.57	20.02	380.2	545.6
9/5/97	108964.2	145027.5			7.94	19.10	382.0	549.9
9/8/97	109783.8	146707.7			9.20	22.30	384.7	556.8
9/9/97	110100.7	147380.2			9.97	25.02	385.8	559.5
9/10/97	110363	147925.3	0.55	0.57	8.09	19.05	386.7	561.7
9/15/97	111618.8	150451.2			8.95	20.41	391.1	572.0
9/16/97	111867	150941.3			6.55	14.65	392.0	574.0
9/17/97	112061.8	151343.6			7.34	17.19	392.7	575.6
9/18/97	112326	151879.3			8.39	19.27	393.6	577.8
9/19/97	112547.7	152415.9			10.54	28.91	394.4	580.0
9/22/97	113381.9	153987.5			8.71	18.60	397.3	586.4
9/23/97	113582.1	154450.7			7.85	20.58	398.0	588.3
9/24/97	113735.3	155024.9			4.85	20.59	398.6	590.6
9/25/97	114000.5	155818.2			9.85	33.38	399.5	593.8
9/30/97	115173	157166.1			8.11	23.30	403.7	606.1
10/2/97	116266.2	157700.8	0.49	0.57	5.02	9.88	404.8	608.3
10/3/97	116419.8	158233.6			5.26	19.71	405.4	610.5
10/7/97	117108.8	160231.8			6.28	19.68	407.9	618.6
10/8/97	117230.5	160485			6.22	13.98	408.4	619.6
10/10/97	117534.5	161066.7			5.45	11.26	409.5	622.0
10/14/97	118211.7	162296.9			5.78	11.34	412.0	627.0
10/16/97	118486.3	162756.3			5.53	10.00	413.1	628.8
10/17/97	118651.5	163031.1			5.95	10.69	413.7	629.9
10/19/97	119019.5	163659.8			5.65	10.42	415.0	632.5
10/20/97	119166.8	163910.9			5.38	9.91	415.6	633.5
10/22/97	119675.4	164642.3			9.21	14.30	417.5	636.5
10/27/97	120574	166872.9			6.92	18.56	420.8	645.5
10/29/97	120796.5	167520.2			3.77	11.85	421.6	648.2
11/2/97	121553.5	169574.6			6.42	18.81	424.4	656.5
11/3/97	121746.8	170109.8			7.24	21.65	425.2	658.7
11/4/97	121938.2	170630.9		0.57	7.17	21.19	425.9	660.8
11/5/97	122069.7	171094.2		0.59	4.79	18.86	426.3	662.7
11/9/97	122652.2	173082.6	0.55	0.54	5.63	18.54	428.5	670.8
11/10/97	122760	173424.2			5.08	15.56	428.9	672.1
11/12/97	123076.3	174441.4			5.58	17.35	430.2	676.3
11/18/97	123934.4	176977.3	0.56	0.55	5.63	16.14	433.6	686.1
11/19/97	124107.2	177450.7	0.53		5.34	15.29	434.2	688.0
11/23/97	124713.2	179016.2	0.52	0.57	5.77	15.47	436.5	694.3

Gas Production Details

Date	Landfill Gas Volume (100 ft^3)		Methane Content (%)		Methane Gas Flowrate (standard ft^3/min)		Cumulative Methane Volume Per Pound of Dry Waste 10^{-3} (scf/dry lb)	
	Control	Enhanced	Control	Enhanced	Control	Enhanced	Control	Enhanced
11/24/97	124855.8	179374.2			4.73	12.31	437.0	695.7
11/25/97	124958.5	179625.2			5.97	15.12	437.4	696.7
11/26/97	125113.7	179992.3	0.56	0.56	10.03	23.91	438.0	698.2
12/1/97	125941.2	181861	0.55	0.57	7.77	15.61	438.9	700.7
12/1/97	125960	181861			7.77	15.61	438.9	700.7
12/4/97	125960	181861	0.55	0.59	7.63	15.67	441.4	706.0
12/4/97	125968.4	181861			7.63	15.67	441.4	706.0
12/5/97	125968.4	181861			7.63	15.67	442.0	707.1
12/11/97	129909.9	181861			7.63	15.67	443.1	710.6
12/12/97	130052.8	182198.2			7.63	15.67	443.6	712.0
12/15/97	130052.8	182198.2			7.63	15.67	445.9	716.8
12/16/97	130052.8	182200.8			7.63	15.67	446.8	718.6
12/19/97	130052.8	182293.2	0.53	0.57	7.48	15.45	449.2	724.0
1/6/98	134409.7	188127.6	0.57	0.61	8.87	12.92	465.8	748.4
1/7/98	134635.1	188373.5			9.72	11.54	466.7	749.5
1/12/98	135802.7	190431.3			8.69	16.67	471.2	758.1
1/21/98	138109.5	194209			9.27	16.52	480.0	773.8
1/22/98	138315.2	194516.4			8.56	13.91	480.8	775.1
1/23/98	138586.2	195021	0.53	0.55	8.02	15.86	481.8	777.2
1/29/98	139859.3	197583.7	0.51	0.53	7.36	15.53	486.4	787.3
1/30/98	140040.3	197982.3			5.81	13.41	487.1	788.8
2/4/98	141148	200370.3	0.47	0.49	7.75	17.49	491.0	797.9
2/4/98	141177.7	200460.5			4.81	15.29	491.1	798.3
2/5/98	141311	200855.4			5.40	16.75	491.7	799.9
2/9/98	142726.7	203267.2			12.65	22.56	496.7	809.2
2/11/98	143244.7	204499.4			8.68	21.62	498.6	813.9
2/13/98	143837.9	205786.8			10.27	23.34	500.7	818.8
2/18/98	145317	208739.5			10.56	22.08	506.0	830.1
2/19/98	145573.6	209387.7			7.85	20.77	507.0	832.8
2/20/98	145793.7	209956.7			9.45	25.58	507.8	835.0
2/23/98	146651.5	211703.4			9.94	21.15	510.9	841.6
2/24/98	146738.8	211945			8.10	23.43	512.0	844.9
2/26/98	146739.2	211947.3	0.54	0.57	9.76	25.08	513.7	849.3
2/26/98	146787.4	212086.2			7.03	21.57	513.8	849.9
2/27/98	147003.1	212086.4			10.78	24.03	514.7	851.7
2/27/98	147025.6	212154			6.05	20.43	514.7	852.0
3/2/98	147659.2	212165.3			7.92	23.15	517.1	856.8
3/3/98	147951.7	212237.5			9.27	10.22	518.2	858.0
3/4/98	148183.5	212928.9			7.90	25.10	519.1	860.8
3/5/98	148346.3	213400.5	0.53	0.56	7.36	22.57	519.7	862.6
3/6/98	148621	214369.8			9.14	34.13	520.5	866.3
3/9/98	149348.1	216679.4	0.48	0.49	7.55	25.98	523.0	874.6
3/10/98	149498.2	217144.3			4.86	16.32	523.5	876.3
3/11/98	149548.2	217289.3			6.62	20.80	524.3	878.9
3/12/98	149564.6	217369.2	0.46	0.52	5.47	29.38	524.7	881.3
3/13/98	149745	217947.5			5.83	20.61	525.3	883.5
3/16/98	150156.1	219190			5.12	17.06	527.0	889.1
3/17/98	150293.2	219713.8	0.52	0.55	5.61	23.37	527.5	891.1
3/18/98	150423.7	220172			3.38	12.96	527.9	892.9
3/19/98	150658.3	220736.7			8.47	22.24	528.7	895.0

Gas Production Details

Date	Landfill Gas Volume ($100\ ft^3$) Control	Landfill Gas Volume ($100\ ft^3$) Enhanced	Methane Content (%) Control	Methane Content (%) Enhanced	Methane Gas Flowrate (standard ft^3/min) Control	Methane Gas Flowrate (standard ft^3/min) Enhanced	Cumulative Methane Volume Per Pound of Dry Waste 10^{-3} (scf/dry lb) Control	Cumulative Methane Volume Per Pound of Dry Waste 10^{-3} (scf/dry lb) Enhanced
3/20/98	150833.2	221162.4			5.71	15.17	529.3	896.6
3/23/98	151393	222950.4			6.53	22.76	531.2	903.4
3/24/98	151501.2	223609.7			3.06	20.36	531.6	905.9
3/26/98	151850.9	224677.8			6.64	22.12	532.8	910.0
3/27/98	151966.5	225211.2			3.50	17.62	533.2	912.0
3/30/98	152753.7	226996.4	0.48	0.56	8.62	22.37	535.8	918.8
3/31/98	152861.6	227475.8			3.29	16.71	536.1	920.6
4/1/98	152993.8	228067.9			4.12	21.13	536.6	922.8
4/2/98	153087.4	228491			3.00	15.52	536.9	924.4
4/3/98	153189.7	228912.9			3.29	15.53	537.2	926.0
4/6/98	153484.6	230233.2			3.10	15.90	538.2	931.0
4/7/98	153589.1	230698.9			3.09	15.76	538.5	932.7
4/8/98	153685	231121.8			3.12	15.73	538.8	934.3
4/9/98	153826.8	231701.8			4.23	19.82	539.3	936.5
4/10/98	153947.3	232191			4.40	20.43	539.7	938.3
4/13/98	154350.2	233794.7			4.38	19.95	541.0	944.4
4/14/98	154480	234301.9	0.47	0.57	4.25	20.17	541.4	946.4
4/15/98	154600.3	234763.8			3.41	15.88	541.8	948.2
4/16/98	154687.3	235100.2			3.02	14.15	542.1	949.6
4/20/98	155137.4	237084.3			3.42	18.32	543.6	957.5
4/21/98	155209.5	237509.7			2.49	17.83	543.8	959.2
4/22/98	155296.2	237938.6			2.62	15.74	544.1	960.9
4/23/98	155397.1	238459.7			2.99	18.74	544.4	962.9
4/24/98	155503.3	238973.8			2.94	17.29	544.7	965.0
4/27/98	155753.9	240139.6	0.48	0.57	2.51	16.33	545.5	969.8
4/28/98	155818	240484			1.84	13.82	545.6	971.2
4/29/98	155889	240892.5			1.87	15.06	545.8	972.9
4/30/98	155946.2	241251.7			1.69	14.89	546.0	974.4
5/1/98	156028.5	241715.9			2.00	15.82	546.3	976.3
5/4/98	156291.5	243057			2.61	18.67	547.0	981.8
5/5/98	156407.9	243589.6			3.01	19.26	547.3	984.0
5/6/98	156506.8	243987.3			2.69	15.15	547.6	985.7
5/7/98	156596.2	244335			2.77	15.08	547.9	987.1
5/8/98	156687.1	244685.1			2.68	14.46	548.2	988.6
5/11/98	156998.4	245839.2			2.83	14.68	549.1	993.3
5/12/98	157112.5	246235.3			2.79	13.58	549.4	995.0
5/13/98	157202.8	246552.3			2.81	13.80	549.6	996.3
5/14/98	157294.8	246875.7	0.46	0.59	2.65	14.09	549.9	997.6
5/16/98	157337.7	247218.2			0.55	6.66	550.0	999.0
5/18/98	157444.9	248083.8			1.43	17.42	550.3	1002.6
5/19/98	157480.3	248368.9			0.87	10.59	550.4	1003.8
5/20/98	157497.2	248711.5			0.39	11.91	550.4	1005.2
5/26/98	157868.7	250889.2	0.46	0.57	1.77	14.15	551.5	1013.9
5/27/98	157907.7	251213			1.01	11.48	551.6	1015.1
5/29/98	157979.8	251805.2			1.02	11.45	551.8	1017.5
6/1/98	158092	252686.9			1.02	10.98	552.1	1021.0
6/2/98	158129	252997.2			1.03	11.77	552.2	1022.2
6/3/98	158162.8	253278.7			1.00	11.31	552.3	1023.4
6/3/98	158169.6	253331.3			0.99	10.41	552.4	1023.6
6/4/98	158202.1	253585.4			1.14	12.14	552.4	1024.6

Gas Production Details

Date	Landfill Gas Volume (100 ft^3)		Methane Content (%)		Methane Gas Flowrate (standard ft^3/min)		Cumulative Methane Volume Per Pound of Dry Waste 10^{-3} (scf/dry lb)	
	Control	Enhanced	Control	Enhanced	Control	Enhanced	Control	Enhanced
6/5/98	158241.6	253905.2			1.09	12.04	552.6	1025.8
6/8/98	158333.7	254616.3			0.92	9.67	552.9	1029.1
6/9/98	158362.2	254868	0.48	0.57	0.82	11.50	552.9	1030.1
6/10/98	158392.1	255108.2			0.69	8.74	553.0	1031.0
6/10/98	158397.4	255150.3			0.73	9.19	553.0	1031.2
6/11/98	158421.5	255344.9			0.69	8.85	553.1	1032.0
6/15/98	158533.9	256248.6			0.67	8.55	553.4	1035.6
6/16/98	158543.1	256487.5			0.23	9.50	553.4	1036.5
6/17/98	158568.1	256726.8			0.57	8.65	553.4	1037.5
6/19/98	158618.5	257161.9			0.64	8.74	553.6	1039.2
6/22/98	158702.5	257865.5	0.39	0.57	0.47	9.13	553.7	1042.1
6/23/98	158736.1	258120.2			0.47	8.32	553.8	1043.2
6/25/98	158783	258484.1			0.45	8.02	553.9	1044.7
6/26/98	158801.7	258719.8			0.29	8.41	553.9	1045.7
6/29/98	158836.9	259137.4			0.20	5.48	553.9	1047.4
6/30/98	158843.1	259277.8			0.11	5.99	554.0	1048.0
7/1/98	158899.7	259493.3			0.78	6.90	554.1	1048.8
7/2/98	158947.3	259652.2			0.84	6.49	554.2	1049.5
7/6/98	159135.8	260274.7	0.33	0.58	0.70	6.30	554.4	1052.0
7/7/98	159147	260462.7			0.16	7.14	554.5	1052.8
7/8/98	159158.7	260711.3			0.14	8.26	554.5	1053.8
7/10/98	159222.3	261095.9			0.50	8.16	554.6	1055.4
7/13/98	159264.8	261529.5			0.20	5.65	554.6	1057.1
7/14/98	159323.8	261960.7			0.82	16.26	554.7	1058.9
7/15/98	159335.5	262157.9			0.17	7.64	554.7	1059.7
7/16/98	159346.5	262349.9			0.16	7.56	554.8	1060.5
7/17/98	159354	262543.8			0.10	7.38	554.8	1061.3
7/20/98	159365.4	262950.5			0.05	5.28	554.8	1062.9
7/21/98	159368.7	263023.5	0.32	0.56	0.05	2.53	554.8	1063.2
7/22/98	159379.5	263153.1			0.14	4.11	554.8	1063.7
7/24/98	159397	263385.7			0.13	4.33	554.8	1064.5
7/27/98	159456.2	263910			0.52	11.30	555.0	1068.1
7/28/98	159474.3	264112.9			0.20	5.63	555.0	1068.8
7/31/98	159532.2	264896.8			0.30	9.84	555.1	1071.7
8/3/98	159562.2	265653.8			0.14	8.53	555.1	1074.5
8/4/98	159568.2	265848	0.32	0.55	0.09	6.85	555.2	1075.1
8/5/98	159568.5	266052.1			0.00	5.15	555.2	1075.7
8/7/98	159597.8	266534			0.21	8.05	555.2	1077.3
8/10/98	159676.3	267035.9			0.36	5.35	555.3	1078.9
8/11/98	159703.3	267310.4			0.30	7.18	555.3	1079.8
8/14/98	159773.5	267922.2			0.32	6.59	555.4	1081.8
8/17/98	159845.2	268552.6	0.30	0.45	0.30	6.44	555.5	1084.0
8/21/98	159873.7	269109.3			0.11	4.94	555.6	1086.0
8/24/98	159883.4	269674.2			0.04	5.94	555.6	1088.0
8/25/98	159886.6	269797.8			0.06	5.46	555.6	1088.4
8/26/98	159886.6	269956			0.00	5.27	555.6	1088.9
8/27/98	159886.6	270089.1			0.00	4.31	555.6	1089.4
8/28/98	159886.6	270230.5			0.00	3.77	555.6	1089.9
8/31/98	159886.8	270642			0.00	4.97	555.6	1091.3
9/1/98	159886.8	270775.9	0.34	0.56	0.00	4.99	555.6	1091.9

Gas Production Details

Date	Landfill Gas Volume ($100\ ft^3$)		Methane Content (%)		Methane Gas Flowrate (standard ft^3/min)		Cumulative Methane Volume Per Pound of Dry Waste 10^{-3} (scf/dry lb)	
	Control	Enhanced	Control	Enhanced	Control	Enhanced	Control	Enhanced
9/2/98	159886.8	270995.7			0.00	7.56	555.6	1092.7
9/3/98	159886.8	271193.8			0.00	6.26	555.6	1093.5
9/4/98	159886.8	271342.3			0.00	6.96	555.6	1094.1
9/8/98	159886.9	272086.3			0.00	6.89	555.6	1096.9
9/14/98	159886.9	272909.8			0.00	4.88	555.6	1100.1
9/15/98	159886.9	273114.3	0.33	0.57	0.00	8.70	555.6	1101.0
9/16/98	159886.9	273354.7			0.00	8.35	555.6	1101.9
9/17/98	159886.9	273610.4			0.00	9.06	555.6	1102.9
9/18/98	159886.9	273787.8			0.00	8.38	555.6	1103.6
9/21/98	159886.9	274328.2			0.00	6.39	555.6	1105.6
9/22/98	159886.9	274507.3			0.00	5.31	555.6	1106.3
9/23/98	159886.9	274648.9			0.00	5.75	555.6	1106.8
9/24/98	159886.9	274807.5			0.00	5.61	555.6	1107.4
9/28/98	159886.9	275660.3	0.31	0.61	0.00	7.66	555.6	1110.6
9/29/98	160010.7	275960			1.36	9.18	555.8	1111.8
9/30/98	160109.1	276131.2			1.50	7.28	555.9	1112.4
10/1/98	160211.3	276293.2			1.29	5.71	556.0	1113.0
10/2/98	160211.3	276483.3			0.00	7.77	556.0	1113.7
10/5/98	160211	277094			0.00	6.91	556.0	1116.0
10/6/98	160211.3	277241.7			0.01	6.89	556.0	1116.6
10/12/98	160211.3	278039			0.00	4.74	556.0	1119.6
10/13/98	160211.3	278203			0.00	4.76	556.0	1120.2
10/14/98	160211.3	278387.3	0.29	0.53	0.00	8.01	556.0	1120.9
10/15/98	160211.3	278503.7			0.00	3.61	556.0	1121.3
10/19/98	160211.3	279490.3			0.00	8.59	556.0	1125.0
10/21/98	160211.3	279786.7			0.00	5.88	556.0	1126.0
10/26/98	160211.3	280404.9			0.00	4.35	556.0	1128.3
10/27/98	160211.3	280551.1			0.00	4.29	556.0	1128.9
10/28/98	160211.3	280686.4			0.00	4.48	556.0	1129.4
10/30/98	160211.3	280934.3			0.00	4.48	556.0	1130.3
11/2/98	160211.3	281644.8			0.00	8.08	556.0	1132.9
11/9/98	160211.3	282476.2	0.32	0.53	0.00	3.82	556.0	1135.7
11/10/98	160212.2	282588.7			0.01	3.36	556.0	1136.0
11/13/98	160212.2	282918			0.00	3.40	556.0	1137.1
11/20/98	160212.2	283477.6			0.00	2.64	556.0	1139.0
11/23/98	160212.2	283680.7			0.00	2.05	556.0	1139.7
12/2/98	160212.2	285014.3			0.00	4.64	556.0	1144.1
12/9/98	160212.2	286063			0.00	4.68	556.0	1147.6
12/10/98	160212.2	286156.7	0.32	0.53	0.00	3.19	556.0	1147.8
12/14/98	160212.2	286630.6			0.00	3.22	556.0	1149.3
12/21/98	160212.2	287427.4			0.00	3.24	556.0	1151.6
12/28/98	160212.2	288143			0.00	2.91	556.0	1153.8
1/6/99	160212.2	289543.3			0.00	4.40	556.0	1157.9
1/8/99	160212.2	289814.5	0.32	0.54	0.00	4.63	556.0	1158.8
1/12/99	160212.2	290469.6			0.00	4.83	556.0	1160.9
1/13/99	160212.2	290633.8			0.00	5.16	556.0	1161.5
1/20/99	160212.2	291797.4			0.00	5.04	556.0	1165.2
1/27/99	160212.2	292599.8			0.00	3.53	556.0	1167.9
2/2/99	160212.2	293118.1			0.00	2.70	556.0	1169.5
2/10/99	160212.2	294094.2			0.00	3.83	556.0	1172.7

Gas Production Details

Date	Landfill Gas Volume (100 ft^3)		Methane Content (%)		Methane Gas Flowrate (standard ft^3/min)		Cumulative Methane Volume Per Pound of Dry Waste 10^{-3} (scf/dry lb)	
	Control	Enhanced	Control	Enhanced	Control	Enhanced	Control	Enhanced
2/18/99	160212.2	295304.3			0.00	4.63	556.0	1176.6
3/5/99	160212.2	297703.4			0.00	4.91	556.0	1184.4
3/19/99	160212.2	299278.8			0.00	3.67	556.0	1189.9
3/25/99	160212.2	300069.1			0.00	4.43	556.0	1192.6
4/2/99	160212.2	301101.6			0.00	4.19	556.0	1196.2
4/8/99	160212.2	301644.8			0.00	3.01	556.0	1198.1
4/16/99	160212.2	302579			0.00	3.90	556.0	1201.3
4/26/99	160212.2	303878.2			0.00	4.15	556.0	1205.8
5/3/99	160212.2	304745.2			0.00	4.12	556.0	1208.8
5/20/99	160212.2	306288.8			0.00	3.00	556.0	1214.2
9/7/99	161561.2	315965			0.13	2.84	557.8	1247.1
9/8/99	161593	316066			0.31	2.93	557.8	1247.5
9/9/99	161624	316161			0.33	3.06	557.9	1247.8
9/10/99	161656	316261			0.34	3.15	557.9	1248.2
9/13/99	161751	316554			0.35	3.18	558.0	1249.2
9/14/99	161781	316646			0.34	3.10	558.1	1249.5
9/15/99	161810	316739			0.29	2.81	558.1	1249.8
9/16/99	161841	316832			0.40	3.60	558.1	1250.1
9/17/99	161877	316944			0.39	3.23	558.2	1250.5
9/20/99	161964	317220			0.37	3.09	558.3	1251.5
9/22/99	162018	317395			0.34	2.91	558.4	1252.1
9/23/99	162039	317462			0.36	3.08	558.4	1252.3
9/24/99	162066	317547	0.23	0.54	0.52	2.13	558.5	1252.7
9/27/99	162135	317768			0.56	2.34	558.6	1253.6
9/29/99	162180	317912			0.48	2.03	558.6	1254.1
9/30/99	162188	318007			0.18	2.86	558.6	1254.5
10/1/99	162194	318091			0.15	2.69	558.7	1254.8
10/4/99	162216	318369			0.17	2.78	558.7	1255.9
10/6/99	162225	318515			0.11	2.32	558.7	1256.5
10/7/99	162231	318598			0.18	3.19	558.7	1256.9
10/11/99	162244	318966			0.07	2.62	558.7	1258.3
10/12/99	162244	319049			0.00	2.75	558.7	1258.6
10/13/99	162244	319135			0.00	2.64	558.7	1259.0
10/14/99	162244	319230			0.00	2.91	558.7	1259.4
10/15/99	162244	319310			0.00	2.90	558.7	1259.7
10/18/99	162244	319615			0.00	2.93	558.7	1260.9
10/19/99	162244	319708			0.00	2.88	558.7	1261.3
10/20/99	162244	319796			0.00	2.73	558.7	1261.6
10/21/99	162244	319872			0.00	2.64	558.7	1261.9
10/22/99	162244	319974			0.00	2.71	558.7	1262.3
10/25/99	162244	320267			0.00	2.97	558.7	1263.5
10/28/99	162276	320412			0.26	1.57	558.8	1264.1
10/29/99	162309	320482			0.66	1.82	558.8	1264.3
11/2/99	162413	320706			0.63	1.79	559.0	1265.2
11/4/99	162467	320824			0.66	1.88	559.0	1265.7
11/5/99	162485	320866			0.42	1.28	559.1	1265.9
11/8/99	162562	321045			0.59	1.79	559.2	1266.6
11/9/99	162594	321120			0.75	2.29	559.2	1266.9
11/12/99	162652	321259			0.43	1.35	559.3	1267.4
11/13/99	162700	321301			1.38	1.57	559.4	1267.6

Gas Production Details

Date	Landfill Gas Volume (100 ft^3)		Methane Content (%)		Methane Gas Flowrate (standard ft^3/min)		Cumulative Methane Volume Per Pound of Dry Waste 10^{-3} (scf/dry lb)	
	Control	Enhanced	Control	Enhanced	Control	Enhanced	Control	Enhanced
11/15/99	162717	321411			0.19	1.57	559.4	1268.0
11/16/99	162741	321466			0.58	1.73	559.4	1268.3
11/17/99	162768	321529	0.56	0.33	0.80	2.07	559.5	1268.5
11/18/99	162794	321592			0.69	1.85	559.6	1268.7
11/22/99	162891	321816			0.67	1.72	559.8	1269.4
11/24/99	162934	321919			0.59	1.57	560.0	1269.7
11/29/99	163051	322191			0.67	1.72	560.3	1270.6
11/30/99	163080	322260			0.71	1.87	560.4	1270.8
12/2/99	163130	322376			0.67	1.74	560.5	1271.2
12/6/99	163236	322617			0.78	1.98	560.8	1272.0
12/7/99	163250	322703			0.37	2.55	560.9	1272.3
12/8/99	163264	322776	0.27	0.52	0.22	2.45	560.9	1272.5
12/13/99	163308	323129			0.15	2.49	561.0	1273.9
12/14/99	163319	323209			0.18	2.80	561.0	1274.2
12/16/99	163323	323211			0.03	0.03	561.0	1274.2
12/17/99	163327	323262			0.07	1.74	561.0	1274.4
12/20/99	163414	323639			0.50	4.54	561.2	1275.8
12/21/99	163439	323744			0.42	3.74	561.2	1276.2
12/29/99	163704	324858			0.56	4.95	561.7	1280.4
1/3/00	163880	325254			0.60	2.83	562.0	1281.9
1/4/00	163907	325318			0.56	2.81	562.1	1282.1
1/5/00	163950	325422			0.61	3.07	562.2	1282.5
1/12/00	164100	325784			0.37	1.86	562.4	1283.9
1/13/00	164123	325840			0.39	2.00	562.5	1284.1
1/14/00	164144	325891			0.36	1.82	562.5	1284.3
1/18/00	164230	326081			0.37	1.72	562.7	1285.0
1/20/00	164273	326172			0.37	1.63	562.8	1285.4
1/24/00	164293	326422			0.09	2.30	562.8	1286.3
1/25/00	164293	326433			0.00	0.35	562.8	1286.3
1/26/00	164293	326504			0.00	2.12	562.8	1286.6
1/27/00	164295	326559			0.04	2.15	562.8	1286.8
1/28/00	164301	326606			0.11	1.84	562.8	1287.0
2/1/00	164329	326883			0.11	2.39	562.9	1288.0
2/2/00	164336	326959			0.12	2.78	562.9	1288.3
2/3/00	164352	327037			0.30	3.10	562.9	1288.6
2/4/00	164372	327090			0.38	2.11	563.0	1288.8
2/7/00	164458	327312	0.24	0.51	0.45	2.03	563.1	1289.5
2/8/00	164488	327388			0.43	1.92	563.1	1289.7
2/9/00	164509	327444			0.41	1.91	563.2	1289.9
2/10/00	164562	327487			0.71	1.01	563.3	1290.0
2/14/00	164719	327615			0.66	0.95	563.5	1290.4
2/16/00	164801	327673			0.62	0.77	563.7	1290.5
2/17/00	164854	327709			0.87	1.04	563.8	1290.7
2/18/00	164857	327788			0.04	1.95	563.8	1290.9
2/22/00	164861	328075			0.02	2.05	563.8	1291.7
2/23/00	164861	328153			0.00	2.39	563.8	1292.0
2/24/00	164861	328237			0.00	2.23	563.8	1292.2
2/25/00	164861	328300			0.00	1.67	563.8	1292.4
2/28/00	164861	328511			0.00	2.06	563.8	1293.0
2/29/00	164861	328568			0.00	1.62	563.8	1293.2

Gas Production Details

Date	Landfill Gas Volume (100 ft^3)		Methane Content (%)		Methane Gas Flowrate (standard ft^3/min)		Cumulative Methane Volume Per Pound of Dry Waste 10^{-3} (scf/dry lb)	
	Control	Enhanced	Control	Enhanced	Control	Enhanced	Control	Enhanced
3/2/00	164861	328674			0.00	1.42	563.8	1293.5
3/3/00	164861	328750			0.00	2.71	563.8	1293.7
3/6/00	164861	329056			0.00	2.76	563.8	1294.6
3/7/00	164862	329169			0.02	3.00	563.8	1295.0
3/8/00	164864	329249	0.32	0.31	0.06	3.14	563.8	1295.2
3/9/00	164866	329312			0.06	1.86	563.8	1295.4
3/13/00	164867	329460			0.01	1.03	563.8	1295.9
3/15/00	164867	329517	0.51	0.57	0.00	1.17	563.8	1296.1
3/16/00	164867	329539			0.00	0.94	563.8	1296.2
3/21/00	164867	329687			0.00	1.16	563.8	1296.8
3/23/00	164867	329753			0.00	1.17	563.8	1297.1
3/24/00	164867	329807			0.00	1.79	563.8	1297.3
3/27/00	164867	329942			0.00	1.85	563.8	1297.8
3/28/00	164867	330002			0.00	2.16	563.8	1298.1
3/29/00	164867	330061	0.39	0.55	0.00	1.83	563.8	1298.3
3/30/00	164867	330146			0.00	2.86	563.8	1298.6
4/3/00	164867	330468			0.00	2.65	563.8	1299.6
4/4/00	164867	330570			0.00	2.65	563.8	1300.0
4/5/00	164878	330663	0.42	0.38	0.31	2.26	563.8	1300.2
4/10/00	164922	331163			0.27	2.63	563.9	1301.6
4/12/00	164922	331329	0.43	0.36	0.00	2.02	563.9	1302.0
4/13/00	164922	331445			0.00	2.55	563.9	1302.3
4/14/00	164994	331526			2.10	2.36	564.1	1302.5
4/17/00	165235	331848			1.77	2.37	564.7	1303.3
4/18/00	165302	331936			1.76	2.32	564.9	1303.5
4/20/00	165424	332117			1.56	2.32	565.2	1304.0
4/21/00	165538	332238			2.68	2.85	565.5	1304.3
4/24/00	165863	332583			2.72	2.89	566.3	1305.2
4/26/00	166090	332824	0.27	0.35	1.70	2.90	566.6	1305.8
5/2/00	166575	333601			1.21	3.09	567.4	1307.7
5/4/00	166729	333859			1.07	2.87	567.6	1308.4
5/5/00	166803	333984			1.11	3.00	567.7	1308.7
5/8/00	167026	334353			1.10	2.92	568.1	1309.6
5/15/00	167625	335124			1.33	2.74	569.0	1311.6
5/16/00	167714	335252			1.15	2.64	569.1	1311.9
5/17/00	167798	335372			1.16	2.65	569.3	1312.2
5/19/00	167948	335585			1.15	2.61	569.5	1312.7
5/22/00	168117	335829			0.88	2.03	569.8	1313.3
5/23/00	168172	335907			0.94	2.14	569.9	1313.5
5/24/00	168269	336047			1.18	2.72	570.0	1313.9
5/25/00	168303	336143	0.16	0.35	0.46	2.79	570.1	1314.1
5/31/00	168316	336842	0.42	0.35	0.06	2.86	570.1	1316.0
6/7/00	168316	337604			0.00	2.68	570.1	1318.0
6/8/00	168316	337703			0.00	2.83	570.1	1318.2
6/13/00	168316	338207	0.43	0.37	0.00	2.52	570.1	1319.6
6/19/00	168316	338799			0.00	2.40	570.1	1321.1
6/20/00	168316	338907			0.00	2.56	570.1	1321.4
6/21/00	168316	338981			0.00	2.80	570.1	1321.6
6/22/00	168316	339111			0.00	2.56	570.1	1321.9
6/27/00	168316	339594			0.00	2.50	570.1	1323.2

Gas Production Details

Date	Landfill Gas Volume (100 ft^3)		Methane Content (%)		Methane Gas Flowrate (standard ft^3/min)		Cumulative Methane Volume Per Pound of Dry Waste 10^{-3} (scf/dry lb)	
	Control	Enhanced	Control	Enhanced	Control	Enhanced	Control	Enhanced
7/7/00	168316	340614			0.00	2.51	570.1	1325.9
7/18/00	168316	341799			0.00	2.70	570.1	1329.0
7/19/00	168316	341906			0.00	2.67	570.1	1329.3
7/20/00	168316	342012			0.00	2.59	570.1	1329.5
7/24/00	168316	342410			0.00	2.60	570.1	1330.6
7/25/00	168316	342501			0.00	2.45	570.1	1330.8
7/26/00	168316	342606	0.49	0.33	0.00	2.52	570.1	1331.1
8/1/00	168468	343161			0.74	2.32	570.6	1332.6
8/2/00	168475	343255			0.19	2.19	570.6	1332.8
8/7/00	168540	343764			0.38	2.53	570.8	1334.1

Leachate Sampling Parameters

Enhanced Cell	Units	2/8/96 Result	11/19/96 Result	12/6/96 Result	12/12/96 Result	12/20/96 Result	1/10/97 Result
Field Parameters:							
pH			7.62	5.75	6.65	7.33	7.3
General Chemistry:							
Ammonia as N	mg/L	10.8	3.0	435	355	325	400
Bicarbonate	mg/L	1100.	1110.	5600.	5760	7080.	8040
BOD	mg O/L						
Carbonate	mg/L	<2.6	12.0	<2.6	<2.6	<2.6	<2.6
Chemical Oxygen Demand	mg O/L	679	31.9	20300	20000	13100	9250
Chloride	mg/L	93.4	104	1060			
Dissolved Boron	µg/L						
Dissolved Phosphorous	mg/L						
Dissolved Si as SiO2	mg/L	23	47	91			
Hydroxide	mg/L	<0.8	<0.8	<0.8	<0.8	<0.8	<0.8
Nitrate/Nitrite as N	mg/L	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Sulfate	mg/L	43	7.0	1040	76	16.0	32.0
Total (Non-Volatile) Organic Carbon	mg/L	188	9.8	9830	6620	3990	1580
Total Acidity as CaCO3	mg/L	<5.0	<5.0	4590			
Total Alkalinity as CaCO3	mg/L	901	930	19800	4720	5800	6590
Total Dissolved Solids @ 180 C	mg/L	1460	1100	19800	15000	10900	11200.
Total Kjeldahl Nitrogen	mg/L	21	4.0	673	500	430	573
Total Phosphorus	mg/L	1.7	2.9	32	28	20	29
Total Sulfide	mg/L	12.2	<0.05	2.2	13.0	2.6	4.0
Metals:							
Dissolved Aluminum	µg/L	<3.2	<6.4	1170.			
Dissolved Antimony	µg/L	<0.08	<1.0	17			
Dissolved Arsenic	µg/L	6.4	6.9	174			
Dissolved Barium	µg/L	196.	320.	318.			
Dissolved Beryllium	µg/L	<1.4	<1.3	<0.083			
Dissolved Cadmium	µg/L	<0.1	<1.0	<0.14			
Dissolved Calcium	mg/L	78	86	1400			
Dissolved Chromium	µg/L	<5.7	<9.0	182			
Dissolved Cobalt	µg/L	<50	<3.7	166.			
Dissolved Copper	µg/L	<4.0	<7.3	<10.			
Dissolved Iron	µg/L	1320.	<17	152000.			
Dissolved Lead	µg/L	<.011	<5.	<0.28			
Dissolved Magnesium	mg/L	130	154	1010			
Dissolved Manganese	µg/L	4450.	4900.	41900.			
Dissolved Mercury	µg/L	<0.1	<0.10	<0.1			
Dissolved Molybdenum	µg/L	<3.5	<4.6	<100			
Dissolved Nickel	µg/L	35	6.0	993			
Dissolved Potassium	mg/L	24	4.9	997	694	597	648
Dissolved Selenium	µg/L	<0.5	<0.5	<1.0			
Dissolved Silver	µg/L	<4.8	<7.3	<0.026			
Dissolved Sodium	mg/L	164	109	1030.			
Dissolved Thallium	µg/L	<0.07	<0.26	<0.023			
Dissolved Tin	µg/L	<0.13	<1	20			
Dissolved Vanadium	µg/L	<5.4	<5.4	65.			
Dissolved Zinc	µg/L	30.	114.	88			
Volatile Organic Compounds (VOC):							
Acetone	µg/L						
Acrylonitrile	µg/L						

Leachate Sampling Parameters

Enhanced Cell	Units	1/24/97 Result	2/6/97 Result	2/21/97 Result	3/6/97 Result	3/21/97 Result	4/11/97 Result
Field Parameters:							
pH		8.47	7.41	7.41	7.08		
General Chemistry:							
Ammonia as N	mg/L	345	285	490	260	450	385
Bicarbonate	mg/L	7100	7250	8580	5910.	7470.	6450
BOD	mg O/L						
Carbonate	mg/L	<2.6	<2.6	<2.6	<2.6	<2.6	<2.6
Chemical Oxygen Demand	mg O/L	5920	5020	6540	2960	3150	2860
Chloride	mg/L	1270					
Dissolved Boron	µg/L						
Dissolved Phosphorous	mg/L						
Dissolved Si as SiO2	mg/L	63					
Hydroxide	mg/L	<0.8	<.8	<0.8	<0.8	<0.8	<0.8
Nitrate/Nitrite as N	mg/L	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Sulfate	mg/L	6.4	7.2	9.0	20.6	3.2	6.0
Total (Non-Volatile) Organic Carbon	mg/L	1150	1780	1030	781	430	611
Total Acidity as CaCO3	mg/L						
Total Alkalinity as CaCO3	mg/L	5920	5950	7030	4840	6120	5290
Total Dissolved Solids @ 180 C	mg/L	9650	8550	10800	6900	8200	7600
Total Kjeldahl Nitrogen	mg/L	518	586	778	418	614	546
Total Phosphorus	mg/L	9.4	10.7	11.7	9.8	7.8	7.1
Total Sulfide	mg/L	7.4	6.8	4.4	3.8	1.2	<0.05
Metals:							
Dissolved Aluminum	µg/L	1080					
Dissolved Antimony	µg/L	<200					
Dissolved Arsenic	µg/L	98					
Dissolved Barium	µg/L	409					
Dissolved Beryllium	µg/L	<0.83					
Dissolved Cadmium	µg/L	<20					
Dissolved Calcium	mg/L	480					
Dissolved Chromium	µg/L	167					
Dissolved Cobalt	µg/L	<100					
Dissolved Copper	µg/L	<6.3					
Dissolved Iron	µg/L	933					
Dissolved Lead	µg/L	<19					
Dissolved Magnesium	mg/L	758.					
Dissolved Manganese	µg/L	4000					
Dissolved Mercury	µg/L	<.01					
Dissolved Molybdenum	µg/L	<3.9					
Dissolved Nickel	µg/L	269					
Dissolved Potassium	mg/L	644	660	890	514	714	644
Dissolved Selenium	µg/L	<200					
Dissolved Silver	µg/L	<9.3					
Dissolved Sodium	mg/L	944.					
Dissolved Thallium	µg/L	<200					
Dissolved Tin	µg/L	19					
Dissolved Vanadium	µg/L	106					
Dissolved Zinc	µg/L	99					
Volatile Organic Compounds (VOC):							
Acetone	µg/L						
Acrylonitrile	µg/L						

Leachate Sampling Parameters

Enhanced Cell	Units	4/25/97 Result	5/9/97 Result	5/28/97 Result	6/11/97 Result	6/25/97 Result	7/9/97 Result
Field Parameters:							
pH				7.15			
General Chemistry:							
Ammonia as N	mg/L	220	105	324	360	332	320
Bicarbonate	mg/L	5450.	5730	5750	5700.	5480	5300
BOD	mg O/L				187	214	203
Carbonate	mg/L	<2.6	<2.6	<2.6	<2.6	<2.6	<2.6
Chemical Oxygen Demand	mg O/L	2150.	2350	2470	2600.	2630	1590
Chloride	mg/L	1040					
Dissolved Boron	µg/L						
Dissolved Phosphorous	mg/L						
Dissolved Si as SiO2	mg/L	66					
Hydroxide	mg/L	<0.8	<0.8	<0.8	<0.8	<0.8	<0.8
Nitrate/Nitrite as N	mg/L	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Sulfate	mg/L	10.0	8.8	8.8	5.6	5.6	31.2
Total (Non-Volatile) Organic Carbon	mg/L	686	6.2	788	47.	793	716.
Total Acidity as CaCO3	mg/L						
Total Alkalinity as CaCO3	mg/L	4470	4700.	4720	4670	4490	4340
Total Dissolved Solids @ 180 C	mg/L	6420.	6840.	6960.	7240	6800	6760
Total Kjeldahl Nitrogen	mg/L	234	381	350	458	393	410
Total Phosphorus	mg/L	6.3	6.8	6.6	7.3	7.9	6.4
Total Sulfide	mg/L	<0.05	4.7	2.3	6.3	4.7	16.1
Metals:							
Dissolved Aluminum	µg/L	253.					
Dissolved Antimony	µg/L	<12					
Dissolved Arsenic	µg/L	<19					
Dissolved Barium	µg/L	694.					
Dissolved Beryllium	µg/L	<0.83					
Dissolved Cadmium	µg/L	<3.5					
Dissolved Calcium	mg/L	400					
Dissolved Chromium	µg/L	106.					
Dissolved Cobalt	µg/L	<100					
Dissolved Copper	µg/L	<20					
Dissolved Iron	µg/L	1140.					
Dissolved Lead	µg/L	<15					
Dissolved Magnesium	mg/L	434					
Dissolved Manganese	µg/L	2420.					
Dissolved Mercury	µg/L	<0.1					
Dissolved Molybdenum	µg/L	<3.9					
Dissolved Nickel	µg/L	222.					
Dissolved Potassium	mg/L	504	476	573	535	537	475
Dissolved Selenium	µg/L	<25					
Dissolved Silver	µg/L	<9.3					
Dissolved Sodium	mg/L	916					
Dissolved Thallium	µg/L	<25					
Dissolved Tin	µg/L	<3					
Dissolved Vanadium	µg/L	57.					
Dissolved Zinc	µg/L	200.					
Volatile Organic Compounds (VOC):							
Acetone	µg/L						
Acrylonitrile	µg/L						

Leachate Sampling Parameters

Enhanced Cell	Units	7/23/97 Result	8/13/97 Result	8/26/97 Result	9/10/97 Result	9/24/97 Result	12/17/97 Result
Field Parameters:							
pH		7.09	7.12	7.1	7.08	7.22	7.19
General Chemistry:							
Ammonia as N	mg/L	320	296	360	354.	376.	376
Bicarbonate	mg/L	5470.	5200		5220	4990	5080
BOD	mg O/L	213	165		147	183	
Carbonate	mg/L	<2.6	<2.6		<2.6	<2.6	<2.6
Chemical Oxygen Demand	mg O/L	2770	2840	2880	2920.	3340.	3060
Chloride	mg/L	1400.					
Dissolved Boron	µg/L						
Dissolved Phosphorous	mg/L						
Dissolved Si as SiO2	mg/L	67					76
Hydroxide	mg/L	<0.8	<0.8		<0.8	<0.8	<0.8
Nitrate/Nitrite as N	mg/L	<0.05	<0.05	<0.05	<0.05	<0.2	<0.05
Sulfate	mg/L	14.0		53	156.	80.5	27
Total (Non-Volatile) Organic Carbon	mg/L	850	915	974	1030.	1220	1180
Total Acidity as CaCO3	mg/L						
Total Alkalinity as CaCO3	mg/L	4490	4270	4030	4280	4020	4170
Total Dissolved Solids @ 180 C	mg/L	6700.		7200	7140	7280.	6920
Total Kjeldahl Nitrogen	mg/L	385.	400	410	435	481	508
Total Phosphorus	mg/L	2.8	7.4	7.3	8.2	6.8	7.9
Total Sulfide	mg/L	38.	18.3	27	18.9	23.	22
Metals:							
Dissolved Aluminum	µg/L	391.					409.
Dissolved Antimony	µg/L	<200					<100
Dissolved Arsenic	µg/L	141					<19
Dissolved Barium	µg/L	693.					637.
Dissolved Beryllium	µg/L	<0.44					<0.44
Dissolved Cadmium	µg/L	<4.1					<4.1
Dissolved Calcium	mg/L	239					232.
Dissolved Chromium	µg/L	136.					137.
Dissolved Cobalt	µg/L	<100					64.
Dissolved Copper	µg/L	<4					<4.0
Dissolved Iron	µg/L	199.					312.
Dissolved Lead	µg/L	<18					<18
Dissolved Magnesium	mg/L	392					327
Dissolved Manganese	µg/L	1740.					1370.
Dissolved Mercury	µg/L	<0.1					<0.10
Dissolved Molybdenum	µg/L	<3.7					<50
Dissolved Nickel	µg/L	322.					343.
Dissolved Potassium	mg/L	224		608	676	574	614
Dissolved Selenium	µg/L	<21					<21
Dissolved Silver	µg/L	<5					<5.0
Dissolved Sodium	mg/L	408					1200.
Dissolved Thallium	µg/L	<17					<100
Dissolved Tin	µg/L	<3					13
Dissolved Vanadium	µg/L	64.					61.
Dissolved Zinc	µg/L	<2					50.
Volatile Organic Compounds (VOC):							
Acetone	µg/L						
Acrylonitrile	µg/L						

Leachate Sampling Parameters

Enhanced Cell	Units	3/13/98 Result	6/17/98 Result	10/7/98 Result	1/3/00 Result	4/11/00 Result	5/31/00 Result
Field Parameters:							
pH		7.21	7.26	7.17	7.69	6.91	7.1
General Chemistry:							
Ammonia as N	mg/L	415	444.	529	640	575	499
Bicarbonate	mg/L	4630.	5210			4650	4450
BOD	mg O/L	140	163	80	153	81	87
Carbonate	mg/L	<2.6	<2.6				<5.0
Chemical Oxygen Demand	mg O/L	3130	2980	3120	3550	3100	2790
Chloride	mg/L					2080	2160
Dissolved Boron	µg/L					9600	8600
Dissolved Phosphorous	mg/L					8.2	6.7
Dissolved Si as SiO2	mg/L	73.	69		59		
Hydroxide	mg/L	<0.8	<0.8				<5.0
Nitrate/Nitrite as N	mg/L	<0.05	<0.05	<0.05	<0.5	0.13	<0.075
Sulfate	mg/L	30	<0.16	25	76	<1.0	16.7
Total (Non-Volatile) Organic Carbon	mg/L	1130	1080.	1690	1200	1010	8440
Total Acidity as CaCO3	mg/L						
Total Alkalinity as CaCO3	mg/L	3800	4270	4190	4910	4650	4450
Total Dissolved Solids @ 180 C	mg/L	7500	7450	7650	9000	8360	8280
Total Kjeldahl Nitrogen	mg/L	450	545	564	860	35.5	579
Total Phosphorus	mg/L	7.1	6.0	6.4	110	7.4	6.6
Total Sulfide	mg/L	14.	25.	27	5.2	9.4	<.070
Metals:							
Dissolved Aluminum	µg/L	370.	208.		500	250	<1000
Dissolved Antimony	µg/L	<80	8.2		<500	3.2	3.4
Dissolved Arsenic	µg/L	<8.	68		66	69	67
Dissolved Barium	µg/L	698.	648.		990	1100	1300
Dissolved Beryllium	µg/L	<0.2	0.54		<1.6	<0.11	<0.11
Dissolved Cadmium	µg/L	<5.6	0.92		<20	<0.10	<0.10
Dissolved Calcium	mg/L	220.	198			138	135
Dissolved Chromium	µg/L	129.	138.		200	150	140
Dissolved Cobalt	µg/L	<59	63.		<250	58	56
Dissolved Copper	µg/L	<4.9	<1.4		<20	750	2.8
Dissolved Iron	µg/L	504.	206.		1100	450	540
Dissolved Lead	µg/L	<9.9	1.4		<50	19	<0.15
Dissolved Magnesium	mg/L	307	294			395	443
Dissolved Manganese	µg/L	1170.	1060.		700	850	900
Dissolved Mercury	µg/L	<0.10	0.10		<0.1	<0.049	
Dissolved Molybdenum	µg/L	<4.1	<4.1		<20	5.7	≤ 4.6
Dissolved Nickel	µg/L	328.	298		380	320	320
Dissolved Potassium	mg/L	598	559	565	700	634	552
Dissolved Selenium	µg/L	<120	<1.0		<10	≤ 2.0	≤ 2.0
Dissolved Silver	µg/L	<4.8	<0.11		<20	≤ 1.0	≤ 1.0
Dissolved Sodium	mg/L	1190.	1100			1340	1280
Dissolved Thallium	µg/L	<16.	0.74		<80	<0.1	<.10
Dissolved Tin	µg/L	<9.2	6.4		<20	≤ 100	< 22
Dissolved Vanadium	µg/L	60.	47.		100	82	≤ 250
Dissolved Zinc	µg/L	132	36		<50	360	52
Volatile Organic Compounds (VOC):							
Acetone	µg/L					<50	~
Acrylonitrile	µg/L					<500	<100

Leachate Sampling Parameters

Enhanced Cell	Units	2/8/96 Result	11/19/96 Result	12/6/96 Result	12/12/96 Result	12/20/96 Result	1/10/97 Result
Benzene	µg/L	5.0	<0.08	9.8			
Bromobenzene	µg/L	<0.07	<0.07	<0.07			
Bromochloromethane	µg/L	<0.08	<0.08	<0.08			
Bromodichloromethane	µg/L	<0.08	<0.08	<0.08			
Bromoform	µg/L	<0.15	<0.15	<0.15			
Bromomethane	µg/L	<0.20	<0.20	<0.20			
Carbon Disulfide							
Carbon Tetrachloride	µg/L	<0.11	<0.11	<0.11			
Chlorobenzene	µg/L	<0.25	<0.25	<0.25			
Chloroethane	µg/L	2.7	<0.08	6.3			
Chloroform	µg/L	<0.06	<0.06	<0.06			
Chloromethane	µg/L	<0.15	<0.15	<0.15			
cis-1,2-Dichloroethene	µg/L	3.2	<0.09	10			
cis-1,3-Dichloropropene	µg/L		<0.17	<0.17			
Dibromochloromethane	µg/L	<0.11	<0.11	<0.11			
Dibromomethane	µg/L	<0.10	<0.1	<0.10			
Dichlorodifluoromethane	µg/L	<2.0	<0.09	<2			
Ethylbenzene	µg/L	29	.92	23			
Ethyl Ether							
Hexachlorobutadiene	µg/L	<0.13	<0.13	<0.13			
Idomethane	µg/L						
Isopropylbenzene	µg/L	<2.0	<0.06	<2			
Methylene Chloride	µg/L	6.7	<0.08	67			
Naphthalene	µg/L	<0.11	<0.11	**2.1**			
Methyl tert-butyl ether (MTBE)	µg/L						
m-Xylene & p-Xylene	µg/L						
n-Butylbenzene	µg/L	<0.08	<0.08	<0.08			
n-Propylbenzene	µg/L	<2.0	<0.07	<2			
o-Xylene							
p-Isopropyltoluene	µg/L	41	<0.06	9.3			
sec-Butylbenzene	µg/L	<0.07	<0.07	<0.07			
Styrene	µg/L	<0.07	<0.07	9.4			
tert-Butylbenzene	µg/L	<0.07	<0.07	<0.07			
Tetrachloroethene	µg/L	<0.16	<0.16	<2			
Tetrahydrofuran							
Toluene	µg/L	150	<0.5	160			
Total Xylenes	µg/L	75	2.6	120			
trans-1,2-Dichloroethene	µg/L	<0.09	<0.09	<0.09			
trans-1,3-Dichloropropene	µg/L		<0.17	<0.17			
trans-1,4-Dichloro-2-butene	µg/L						
Trichloroethene	µg/L	<0.09	<0.09	3.0			
Trichlorofluoromethane (Freon 11)	µg/L	<0.07	<0.07	<0.07			
Vinyl Acetate	µg/L						
Vinyl Chloride	µg/L	4.1	1.2	<2			
1,1-Dichloroethane	µg/L	4.4	1.2	9.6			
1,1-Dichloroethene	µg/L	<0.11	<0.11	<0.11			
1,1-Dichloropropene	µg/L	<0.09	<0.09	<0.09			
VOCs Continued:							
1,2-Dibromo-3-chloropropane (DBCP)	µg/L	<0.37	<0.37	<0.37			
1,2-Dibromoethane (EDB)	µg/L	<0.06	<0.06	<0.06			
1,2-Dichlorobenzene	µg/L	<0.12	<0.12	<0.12			
1,2-Dichloroethane	µg/L	<0.12	<0.12	2.6			
1,2-Dichloropropane	µg/L	<0.09	<0.09	<0.09			

Leachate Sampling Parameters

Enhanced Cell	Units	1/24/97 Result	2/6/97 Result	2/21/97 Result	3/6/97 Result	3/21/97 Result	4/11/97 Result
Benzene	µg/L	2.6					
~~Bromobenzene~~	~~µg/L~~	<0.07					
Bromochloromethane	µg/L	<0.08					
Bromodichloromethane	µg/L	<0.08					
Bromoform	µg/L	<0.15					
Bromomethane	µg/L	<0.20					
Carbon Disulfide							
Carbon Tetrachloride	µg/L	<0.11					
Chlorobenzene	µg/L	<0.25					
Chloroethane	µg/L	<0.08					
Chloroform	µg/L	<0.06					
Chloromethane	µg/L	<0.15					
cis-1,2-Dichloroethene	µg/L	<2					
cis-1,3-Dichloropropene	µg/L	<0.17					
Dibromochloromethane	µg/L	<0.11					
Dibromomethane	µg/L	<0.10					
Dichlorodifluoromethane	µg/L	<0.09					
Ethylbenzene	µg/L	10					
Ethyl Ether							
Hexachlorobutadiene	µg/L	<0.13					
Idomethane	µg/L						
Isopropylbenzene	µg/L	<0.06					
Methylene Chloride	µg/L	<0.08					
Naphthalene	µg/L	<2					
Methyl tert-butyl ether (MTBE)	µg/L						
m-Xylene & p-Xylene	µg/L						
n-Butylbenzene	µg/L	<0.08					
n-Propylbenzene	µg/L	<0.07					
o-Xylene							
p-Isopropyltoluene	µg/L	17					
sec-Butylbenzene	µg/L	<0.07					
Styrene	µg/L	<0.07					
tert-Butylbenzene	µg/L	<0.07					
Tetrachloroethene	µg/L	<0.16					
Tetrahydrofuran							
Toluene	µg/L	75					
Total Xylenes	µg/L	46					
trans-1,2-Dichloroethene	µg/L	<0.09					
trans-1,3-Dichloropropene	µg/L	<0.17					
trans-1,4-Dichloro-2-butene	µg/L						
Trichloroethene	µg/L	<0.09					
Trichlorofluoromethane (Freon 11)	µg/L	<0.07					
Vinyl Acetate	µg/L						
Vinyl Chloride	µg/L	2.2					
1,1-Dichloroethane	µg/L	<0.08					
1,1-Dichloroethene	µg/L	<0.11					
1,1-Dichloropropene	µg/L	<0.09					
VOCs Continued:							
1,2-Dibromo-3-chloropropane (DBCP)	µg/L	<0.37					
1,2-Dibromoethane (EDB)	µg/L	<0.06					
1,2-Dichlorobenzene	µg/L	<0.12					
1,2-Dichloroethane	µg/L	<0.12					
1,2-Dichloropropane	µg/L	<0.09					

Leachate Sampling Parameters

Enhanced Cell	Units	4/25/97 Result	5/9/97 Result	5/28/97 Result	6/11/97 Result	6/25/97 Result	7/9/97 Result
Benzene	µg/L	4.5					
~~Bromobenzene~~	~~µg/L~~	<0.07					
Bromochloromethane	µg/L	<0.08					
Bromodichloromethane	µg/L	<0.08					
Bromoform	µg/L	<0.15					
Bromomethane	µg/L	<0.2					
Carbon Disulfide							
Carbon Tetrachloride	µg/L	<0.11					
Chlorobenzene	µg/L	<0.25					
Chloroethane	µg/L	<0.08					
Chloroform	µg/L	<0.06					
Chloromethane	µg/L	<0.15					
cis-1,2-Dichloroethene	µg/L	<3					
cis-1,3-Dichloropropene	µg/L	<0.17					
Dibromochloromethane	µg/L	<0.11					
Dibromomethane	µg/L	<0.1					
Dichlorodifluoromethane	µg/L	<0.09					
Ethylbenzene	µg/L	17					
Ethyl Ether							
Hexachlorobutadiene	µg/L	<0.13					
Idomethane	µg/L						
Isopropylbenzene	µg/L	<3					
Methylene Chloride	µg/L	<0.08					
Naphthalene	µg/L	<3					
Methyl tert-butyl ether (MTBE)	µg/L						
m-Xylene & p-Xylene	µg/L						
n-Butylbenzene	µg/L	<0.08					
n-Propylbenzene	µg/L	<3					
o-Xylene							
p-Isopropyltoluene	µg/L	40					
sec-Butylbenzene	µg/L	<0.07					
Styrene	µg/L	5.0					
tert-Butylbenzene	µg/L	<0.07					
Tetrachloroethene	µg/L	<0.16					
Tetrahydrofuran							
Toluene	µg/L	120					
Total Xylenes	µg/L	67					
trans-1,2-Dichloroethene	µg/L	<0.09					
trans-1,3-Dichloropropene	µg/L	<0.17					
trans-1,4-Dichloro-2-butene	µg/L						
Trichloroethene	µg/L	<0.09					
Trichlorofluoromethane (Freon 11)	µg/L	<0.07					
Vinyl Acetate	µg/L						
Vinyl Chloride	µg/L	5.3					
1,1-Dichloroethane	µg/L	3.0					
1,1-Dichloroethene	µg/L	<0.11					
1,1-Dichloropropene	µg/L	<0.09					
VOCs Continued:							
1,2-Dibromo-3-chloropropane (DBCP)	µg/L	<0.37					
1,2-Dibromoethane (EDB)	µg/L	<0.06					
1,2-Dichlorobenzene	µg/L	<0.12					
1,2-Dichloroethane	µg/L	<0.12					
1,2-Dichloropropane	µg/L	<0.09					

Leachate Sampling Parameters

Enhanced Cell	Units	7/23/97 Result	8/13/97 Result	8/26/97 Result	9/10/97 Result	9/24/97 Result	12/17/97 Result
Benzene	µg/L	2.3					1.7
~~Bromobenzene~~	~~µg/L~~	<0.07					<0.07
Bromochloromethane	µg/L	<0.08					<0.08
Bromodichloromethane	µg/L	<0.08					<0.08
Bromoform	µg/L	<0.15					<0.15
Bromomethane	µg/L	<0.2					<0.20
Carbon Disulfide							
Carbon Tetrachloride	µg/L	<0.11					<0.11
Chlorobenzene	µg/L	<0.25					<0.25
Chloroethane	µg/L	<0.08					<0.5
Chloroform	µg/L	<0.06					<0.06
Chloromethane	µg/L	<0.15					<0.15
cis-1,2-Dichloroethene	µg/L	2.8					3.5
cis-1,3-Dichloropropene	µg/L	<0.17					<0.17
Dibromochloromethane	µg/L	<0.11					<0.11
Dibromomethane	µg/L	<0.1					<0.10
Dichlorodifluoromethane	µg/L	<0.09					<0.09
Ethylbenzene	µg/L	16					16
Ethyl Ether							
Hexachlorobutadiene	µg/L	<0.13					<0.13
Idomethane	µg/L						
Isopropylbenzene	µg/L	<2					0.73
Methylene Chloride	µg/L	<0.08					<0.08
Naphthalene	µg/L	4.8					6.5
Methyl tert-butyl ether (MTBE)	µg/L						
m-Xylene & p-Xylene	µg/L						
n-Butylbenzene	µg/L	<0.08					<0.08
n-Propylbenzene	µg/L	<2					0.68
o-Xylene							
p-Isopropyltoluene	µg/L	29					25
sec-Butylbenzene	µg/L	<0.07					<0.07
Styrene	µg/L	<0.07					<0.07
tert-Butylbenzene	µg/L	<0.07					<0.07
Tetrachloroethene	µg/L	<0.16					<0.16
Tetrahydrofuran							
Toluene	µg/L	71					37
Total Xylenes	µg/L	83					61
trans-1,2-Dichloroethene	µg/L	<0.09					<0.09
trans-1,3-Dichloropropene	µg/L	<0.17					<0.17
trans-1,4-Dichloro-2-butene	µg/L						
Trichloroethene	µg/L	<0.09					<0.5
Trichlorofluoromethane (Freon 11)	µg/L	<0.07					<0.07
Vinyl Acetate	µg/L						
Vinyl Chloride	µg/L	2.0					2.4
1,1-Dichloroethane	µg/L	<2					1.3
1,1-Dichloroethene	µg/L	<0.11					<0.11
1,1-Dichloropropene	µg/L	<0.09					<0.09
VOCs Continued:							
1,2-Dibromo-3-chloropropane (DBCP)	µg/L	<0.37					<0.37
1,2-Dibromoethane (EDB)	µg/L	<0.06					<0.06
1,2-Dichlorobenzene	µg/L	<0.12					<0.12
1,2-Dichloroethane	µg/L	<0.12					<0.12
1,2-Dichloropropane	µg/L	<0.09					<0.09

Leachate Sampling Parameters

Enhanced Cell	Units	3/13/98 Result	6/17/98 Result	10/7/98 Result	1/3/00 Result	4/11/00 Result	5/31/00 Result
Benzene	µg/L	1.5	1.8	1.2	1.1	<6.5	<10
Bromobenzene	µg/L	<0.07	<0.07	<0.07	<0.057		
Bromochloromethane	µg/L	<0.08	<0.08	<0.08	<0.095	<16	<3.1
Bromodichloromethane	µg/L	<0.08	<0.08	<0.08	<0.10	<7.0	<1.4
Bromoform	µg/L	<0.15	<0.15	<0.15	<0.079	<5.0	<1.0
Bromomethane	µg/L	<0.20	<0.20	<0.20	<0.11	<4.0	<.80
Carbon Disulfide			2.4	3.3		<50	<20
Carbon Tetrachloride	µg/L	<0.11	<0.11	<0.11	<0.065	<7.5	<1.5
Chlorobenzene	µg/L	<0.5	<0.5	<0.25	0.28	<6.0	<1.2
Chloroethane	µg/L	<0.08	<0.08	<0.08	<0.086	<17	<3.4
Chloroform	µg/L	<0.06	<0.06	<0.06	0.59	<36	<7.2
Chloromethane	µg/L	<0.15	<0.15	<0.15	<0.13	<12	<2.5
cis-1,2-Dichloroethene	µg/L	2.4	3	1.8	<0.13	<5.0	<1.0
cis-1,3-Dichloropropene	µg/L	<0.17	<0.17	<0.17	<0.053	<11	<2.2
Dibromochloromethane	µg/L	<0.11	<0.11	<0.11	<0.056	<20	<4.0
Dibromomethane	µg/L	<0.10	<0.10	<0.10	<0.094	<10	<2.1
Dichlorodifluoromethane	µg/L	0.57	0.7	<0.09	<0.085		
Ethylbenzene	µg/L	14	19	12	13	<50	20
Ethyl Ether			1.5	2.8			
Hexachlorobutadiene	µg/L	<0.13	<0.13	<0.13	<0.073		
Idomethane	µg/L					<50	<10
Isopropylbenzene	µg/L	0.78	1.4	0.88	1.4		
Methylene Chloride	µg/L	<0.08	<1.	<0.08	4.3	<18	<3.5
Naphthalene	µg/L	6.1	11	5.3	1.1		
Methyl tert-butyl ether (MTBE)	µg/L				<0.14	<50	<10
m-Xylene & p-Xylene	µg/L					120	110
n-Butylbenzene	µg/L	<0.08	<0.5	<0.08	<0.083		
n-Propylbenzene	µg/L	0.65	1.1	0.57	0.56		
o-Xylene						<50	15
p-Isopropyltoluene	µg/L	25	28	19	16		
sec-Butylbenzene	µg/L	<0.07	<0.07	<0.07	<0.017		
Styrene	µg/L	2.0	<0.07	<0.07	4	<7.5	<1.5
tert-Butylbenzene	µg/L	<0.07	<0.07	<0.07	<0.081		
Tetrachloroethene	µg/L	<0.16	<0.16	<0.16	<0.059	<19	<3.8
Tetrahydrofuran			4.4	120			
Toluene	µg/L	24	29	15	7	<12	<10
Total Xylenes	µg/L	55	53	35	<0.16		
trans-1,2-Dichloroethene	µg/L	<0.09	<0.09	<0.09	<0.13	<5.5	<1.1
trans-1,3-Dichloropropene	µg/L	<0.17	<0.17	<0.17	<0.054	<15	<3.0
trans-1,4-Dichloro-2-butene	µg/L					<50	<10
Trichloroethene	µg/L	<0.5	<0.09	<0.09	49	<16	<3.1
Trichlorofluoromethane (Freon 11)	µg/L	<0.07	<0.07	<0.07	<0.07	<12	<2.3
Vinyl Acetate	µg/L					<50	<10
Vinyl Chloride	µg/L	2.1	3.8	1.5	<0.050	<6.0	<10
1,1-Dichloroethane	µg/L	1.2	1.3	0.93	0.33	<5.0	<1.0
1,1-Dichloroethene	µg/L	<0.11	<0.11	<0.11	<0.075	<18	<3.6
1,1-Dichloropropene	µg/L	<0.09	<0.09	<0.09	<0.072		
VOCs Continued:							
1,2-Dibromo-3-chloropropane (DBCP)	µg/L	<0.37	<0.37	<0.37	<0.40	<48	<9.5
1,2-Dibromoethane (EDB)	µg/L	<0.06	<0.06	<0.06	<0.035	<11	<2.2
1,2-Dichlorobenzene	µg/L	<0.5	<0.5	<0.5	0.33	<7.0	<1.4
1,2-Dichloroethane	µg/L	<0.5	<0.12	<0.12	<0.080	<11	<2.2
1,2-Dichloropropane	µg/L	<0.09	<0.09	<0.09	<0.074	<7.5	<1.5

Leachate Sampling Parameters

Enhanced Cell	Units	2/8/96 Result	11/19/96 Result	12/6/96 Result	12/12/96 Result	12/20/96 Result	1/10/97 Result
1,3-Dichlorobenzene	µg/L	<0.10	<0.10	<0.10			
1,3-Dichloropropane	µg/L	<0.10	<0.10	<0.10			
1,4-Dichlorobenzene	µg/L	2.6	<0.11	7.0			
1,1,1-Trichloroethane	µg/L	<0.10	<0.10	<0.10			
1,1,2-Trichloroethane	µg/L	<0.12	<0.12	<0.12			
1,2,3-Trichlorobenzene	µg/L	<0.12	<0.12	<0.12			
1,2,3-Trichloropropane	µg/L	<0.16	<0.16	<0.16			
1,2,4-Trichlorobenzene	µg/L	<0.11	<0.11	<0.11			
1,2,4-Trimethylbenzene	µg/L	8.1	<0.06	5.0			
1,3,5-Trimethylbenzene	µg/L	2.5	<0.07	<2			
1,1,1,2-Tetrachloroethane	µg/L	<0.08	<0.08	<0.08			
1,1,2,2-Tetrachloroethane	µg/L	<0.06	<0.06	<0.06			
2-Butanone (MEK)	µg/L						
2-Chlorotoluene	µg/L	<0.07	<0.07	<0.07			
2-Hexanone	µg/L						
4-Chlorotoluene	µg/L	<0.11	<0.11	<0.11			
4-Methyl-2-pentanone (MIBK)	µg/L						
2,2-Dichloropropane	µg/L	<0.14	<0.14	<0.14			

Leachate Sampling Parameters

Enhanced Cell	Units	1/24/97 Result	2/6/97 Result	2/21/97 Result	3/6/97 Result	3/21/97 Result	4/11/97 Result
1,3-Dichlorobenzene	µg/L	<0.10					
~~1,3-Dichloropropane~~	~~µg/L~~	<0.10					
1,4-Dichlorobenzene	µg/L	2.8					
1,1,1-Trichloroethane	µg/L	<0.10					
1,1,2-Trichloroethane	µg/L	<0.12					
1,2,3-Trichlorobenzene	µg/L	<0.12					
1,2,3-Trichloropropane	µg/L	<0.16					
1,2,4-Trichlorobenzene	µg/L	<0.11					
1,2,4-Trimethylbenzene	µg/L	2.6					
1,3,5-Trimethylbenzene	µg/L	<2					
1,1,1,2-Tetrachloroethane	µg/L	<0.08					
1,1,2,2-Tetrachloroethane	µg/L	<0.06					
2-Butanone (MEK)	µg/L						
2-Chlorotoluene	µg/L	<0.07					
2-Hexanone	µg/L						
4-Chlorotoluene	µg/L	<0.11					
4-Methyl-2-pentanone (MIBK)	µg/L						
2,2-Dichloropropane	µg/L	<0.14					

Leachate Sampling Parameters

Enhanced Cell	Units	4/25/97 Result	5/9/97 Result	5/28/97 Result	6/11/97 Result	6/25/97 Result	7/9/97 Result
1,3-Dichlorobenzene	µg/L	<0.1					
~~1,3-Dichloropropane~~	~~µg/L~~	<0.1					
1,4-Dichlorobenzene	µg/L	5.4					
1,1,1-Trichloroethane	µg/L	<0.1					
1,1,2-Trichloroethane	µg/L	<0.12					
1,2,3-Trichlorobenzene	µg/L	<0.12					
1,2,3-Trichloropropane	µg/L	<0.16					
1,2,4-Trichlorobenzene	µg/L	<0.11					
1,2,4-Trimethylbenzene	µg/L	6.5					
1,3,5-Trimethylbenzene	µg/L	<3					
1,1,1,2-Tetrachloroethane	µg/L	<0.08					
1,1,2,2-Tetrachloroethane	µg/L	<0.06					
2-Butanone (MEK)	µg/L						
2-Chlorotoluene	µg/L	<0.07					
2-Hexanone	µg/L						
4-Chlorotoluene	µg/L	<0.11					
4-Methyl-2-pentanone (MIBK)	µg/L						
2,2-Dichloropropane	µg/L	<0.14					

Leachate Sampling Parameters

Enhanced Cell	Units	7/23/97 Result	8/13/97 Result	8/26/97 Result	9/10/97 Result	9/24/97 Result	12/17/97 Result
1,3-Dichlorobenzene	µg/L	<0.1					<0.10
~~1,3-Dichloropropane~~	~~µg/L~~	<0.1					<0.10
1,4-Dichlorobenzene	µg/L	8.4					8.4
1,1,1-Trichloroethane	µg/L	<0.1					<0.10
1,1,2-Trichloroethane	µg/L	<0.12					<0.12
1,2,3-Trichlorobenzene	µg/L	<0.12					<0.12
1,2,3-Trichloropropane	µg/L	<0.16					<0.16
1,2,4-Trichlorobenzene	µg/L	<0.11					<0.11
1,2,4-Trimethylbenzene	µg/L	5.4					4.8
1,3,5-Trimethylbenzene	µg/L	<2					1.2
1,1,1,2-Tetrachloroethane	µg/L	<0.08					<0.08
1,1,2,2-Tetrachloroethane	µg/L	<0.06					<0.06
2-Butanone (MEK)	µg/L						
2-Chlorotoluene	µg/L	<0.07					<0.07
2-Hexanone	µg/L						
4-Chlorotoluene	µg/L	<0.11					<0.11
4-Methyl-2-pentanone (MIBK)	µg/L						
2,2-Dichloropropane	µg/L	<0.14					<0.14

Leachate Sampling Parameters

Enhanced Cell	Units	3/13/98 Result	6/17/98 Result	10/7/98 Result	1/3/00 Result	4/11/00 Result	5/31/00 Result
1,3-Dichlorobenzene	µg/L	<0.10	<0.10	<0.10	<0.065		
~~1,3-Dichloropropane~~	~~µg/L~~	<0.10	<0.10	<0.10	<0.078		
1,4-Dichlorobenzene	µg/L	6.8	12	6.3	5.6	<50	<10
1,1,1-Trichloroethane	µg/L	<0.10	<0.10	<0.10	0.96	<20	<4.1
1,1,2-Trichloroethane	µg/L	<0.12	<0.12	<0.12	1.6	<16	<3.1
1,2,3-Trichlorobenzene	µg/L	<0.12	<0.12	<0.12	<0.12		
1,2,3-Trichloropropane	µg/L	<0.16	<0.16	<0.16	<0.23	<15	<3.0
1,2,4-Trichlorobenzene	µg/L	<0.11	<0.11	<0.11	3.8		
1,2,4-Trimethylbenzene	µg/L	4.4	7.2	3.8	<0.062		
1,3,5-Trimethylbenzene	µg/L	1.2	1.9	1.6	<0.07		
1,1,1,2-Tetrachloroethane	µg/L	<0.08	<0.08	<0.08	<0.057	<5.0	<1.0
1,1,2,2-Tetrachloroethane	µg/L	<0.06	<0.06	<0.06	<0.094	<18	<3.7
2-Butanone (MEK)	µg/L					<50	<10
2-Chlorotoluene	µg/L	<0.07	<0.07	<0.07	<0.072		
2-Hexanone	µg/L					<50	<10
4-Chlorotoluene	µg/L	<0.11	1.2	<0.11	<0.061		
4-Methyl-2-pentanone (MIBK)	µg/L					<50	<10
2,2-Dichloropropane	µg/L	<0.14	<0.14	<0.14	<0.032		

Leachate Sampling Parameters

Control Cell	Units	12/6/96 Result	1/24/97 Result	2/21/97 Result	3/6/97 Result	3/21/97 Result
Field Parameters						
pH		7.78	8.47	8.16	8.43	
General Chemistry						
Ammonia as N	mg/L	31	9.6	.04	9.0	16
Bicarbonate	mg/L	1990.	1980.	1560	2090.	2460.
BOD	mg O/L					
Carbonate	mg/L	475.	447.	718	333.	160.
Chemical Oxygen Demand	mg O/L	98.5	79.9	50.6	75.8	78.5
Chloride	mg/L	266	234			
Dissolved Si as SiO2	mg/L	55	39			
Hydroxide	mg/L	<0.8	<0.8	<0.8	<0.8	<0.8
Nitrate/Nitrite as N	mg/L	10.4	18.	12.6	27	22
Sulfate	mg/L	1.2	16.0	55.4	3.4	2.2
Total (Non-Volatile) Organic Carbon	mg/L	23	26	16	20	53.7
Total Alkalinity as CO3	mg/L	2420	2370	2470	2270	2280
Total Dissolved Solids @ 180 C	mg/L	2740	2760	2770	2720	2680
Total Kjeldahl Nitrogen	mg/L	45	13.6	2.2	13.0	133
Total Phosphorus	mg/L	1.1	.60	.36	.57	.44
Total Sulfide	mg/L	<0.05	<0.05	<0.05	<0.05	<0.05
Metals:						
Dissolved Aluminum	µg/L	<48	<48			
Dissolved Antimony	µg/L	<2	<12			
Dissolved Arsenic	µg/L	35	<50			
Dissolved Barium	µg/L	1320.	813			
Dissolved Beryllium	µg/L	<0.083	<0.83			
Dissolved Cadmium	µg/L	<0.14	<3.5			
Dissolved Calcium	mg/L	45	18.9			
Dissolved Chromium	µg/L	<8.1	<8.1			
Dissolved Cobalt	µg/L	<4.3	<4.3			
Dissolved Copper	µg/L	<10	<6.3			
Dissolved Iron	µg/L	95.	83			
Dissolved Lead	µg/L	<0.28	<50			
Dissolved Magnesium	mg/L	442	451			
Dissolved Manganese	µg/L	208.	115			
Dissolved Mercury	µg/L	<0.1	<0.1			
Dissolved Molybdenum	µg/L	<3.9	<3.9			
Dissolved Nickel	µg/L	26	<50			
Dissolved Potassium	mg/L	94	83	72	87	83
Dissolved Selenium	µg/L	<1.0	<20			
Dissolved Silver	µg/L	<2	<9.3			
Dissolved Sodium	mg/L	358.	344			
Dissolved Thallium	µg/L	<0.023	<100			
Dissolved Tin	µg/L	5.7	<15			
Dissolved Vanadium	µg/L	<10	<10			
Dissolved Zinc	µg/L	11	18			

Leachate Sampling Parameters

Control Cell	Units	7/23/97 Result	6/17/98 Result	10/8/98 Result
Field Parameters				
pH		8.05	8.75	8.61
General Chemistry				
Ammonia as N	mg/L	24.	12.	16
Bicarbonate	mg/L	2420.	1770	
BOD	mg O/L	67.2	20	<1.0
Carbonate	mg/L	161.	208	
Chemical Oxygen Demand	mg O/L	110	93.	91
Chloride	mg/L	318		
Dissolved Si as SiO2	mg/L	58		
Hydroxide	mg/L	<0.8	<0.8	
Nitrate/Nitrite as N	mg/L	10.9	24	25
Sulfate	mg/L	1.4	<2.5	<0.16
Total (Non-Volatile) Organic Carbon	mg/L	39	26.	105
Total Alkalinity as CO3	mg/L	2250	1800	1760
Total Dissolved Solids @ 180 C	mg/L	2570.	2440	2460
Total Kjeldahl Nitrogen	mg/L	26.	15.	21
Total Phosphorus	mg/L	.50	0.33	0.52
Total Sulfide	mg/L	<0.05	<0.05	<0.05
Metals:				
Dissolved Aluminum	µg/L	<20		
Dissolved Antimony	µg/L	<100		
Dissolved Arsenic	µg/L	56		
Dissolved Barium	µg/L	1190.		
Dissolved Beryllium	µg/L	<0.44		
Dissolved Cadmium	µg/L	<4.1		
Dissolved Calcium	mg/L	31		
Dissolved Chromium	µg/L	<4		
Dissolved Cobalt	µg/L	<2.7		
Dissolved Copper	µg/L	<4		
Dissolved Iron	µg/L	216.		
Dissolved Lead	µg/L	<18		
Dissolved Magnesium	mg/L	414		
Dissolved Manganese	µg/L	149.		
Dissolved Mercury	µg/L	<0.1		
Dissolved Molybdenum	µg/L	<3.7		
Dissolved Nickel	µg/L	<50		
Dissolved Potassium	mg/L	71		74
Dissolved Selenium	µg/L	<100		
Dissolved Silver	µg/L	<5		
Dissolved Sodium	mg/L	340		
Dissolved Thallium	µg/L	<100		
Dissolved Tin	µg/L	<3		
Dissolved Vanadium	µg/L	<10		
Dissolved Zinc	µg/L	<2		

Leachate Sampling Parameters

Control Cell	**Units**	**12/6/96 Result**	**1/24/97 Result**	**2/21/97 Result**	**3/6/97 Result**	**3/21/97 Result**
Volatile Organic Compounds						
Benzene	µg/L	<0.5	<0.5			
Bromobenzene	µg/L	<0.07	<0.07			
Bromochloromethane	µg/L	<0.08	<0.08			
Bromodichloromethane	µg/L	<0.08	<0.08			
Bromoform	µg/L	<0.15	<0.15			
Bromomethane	µg/L	<0.20	<0.20			
Carbon Tetrachloride	µg/L	<0.11	<0.11			
Chlorobenzene	µg/L	<0.25	<0.25			
Chloroethane	µg/L	1.3	<0.5			
Chloroform	µg/L	<0.06	<0.06			
Chloromethane	µg/L	<0.15	<0.15			
cis-1,2-Dichloroethene	µg/L	<0.5	<0.09			
cis-1,3-Dichloropropene	µg/L	<0.17	<0.17			
Dibromochloromethane	µg/L	<0.11	<0.11			
Dibromomethane	µg/L	<0.10	<0.10			
Dichlorodifluoromethane	µg/L	<0.09	<0.09			
Ethyl Benzene	µg/L	<0.07	<0.07			
Ethyl Ether						
Hexachlorobutadiene	µg/L	<0.13	<0.13			
Isopropylbenzene	µg/L	<0.06	<0.06			
Methylene Chloride	µg/L	<1	<1.			
Methyl-t-butylether						
Naphthalene	µg/L	<0.11	<0.11			
n-Butylbenzene	µg/L	<0.08	<0.08			
n-Propylbenzene	µg/L	<0.07	<0.07			
p-Isopropyltoluene	µg/L	<0.06	<0.06			
sec-Butylbenzene	µg/L	<0.07	<0.07			
Styrene	µg/L	<0.07	<0.07			
tert-Butylbenzene	µg/L	<0.07	<0.07			
Tetrachloroethene	µg/L	<0.16	<0.16			
Toluene	µg/L	<0.07	<0.07			
Total Xylenes	µg/L	<0.13	<0.13			
trans-1,2-Dichloroethene	µg/L	<0.09	<0.09			
trans-1,3-Dichloropropene	µg/L	<0.17	<0.17			
Trichloroethene	µg/L	<0.09	<0.5			
Trichlorofluoromethane	µg/L	<0.07	<0.07			
Vinyl Chloride	µg/L	<0.5	<0.09			
1,1-Dichloroethane	µg/L	1.0	<0.5			
1,1-Dichloroethene	µg/L	<0.11	<0.11			
1,1-Dichloropropene	µg/L	<0.09	<0.09			
1,2-Dibromo-3-chloropropane	µg/L	<0.37	<0.37			
1,2-Dibromoethane	µg/L	<0.06	<0.06			
1,2-Dichlorobenzene	µg/L	<0.12	<0.12			
1,2-Dichloroethane	µg/L	<0.5	<0.12			
1,2-Dichloropropane	µg/L	<0.09	<0.09			
1,3-Dichlorobenzene	µg/L	<0.10	<0.10			
1,3-Dichloropropane	µg/L	<0.10	<0.10			
1,4-Dichlorobenzene	µg/L	<0.11	<0.11			
1,1,1-Trichloroethane	µg/L	<0.10	<0.10			
VOC Continued:						
1,1,2-Trichloroethane	µg/L	<0.12	<0.12			
1,2,3-Trichlorobenzene	µg/L	<0.12	<0.12			

Leachate Sampling Parameters

Control Cell	Units	7/23/97 Result	6/17/98 Result	10/8/98 Result
Volatile Organic Compounds				
Benzene	µg/L	<0.5	<0.08	
Bromobenzene	µg/L	<0.07	<0.07	
Bromochloromethane	µg/L	<0.08	<0.08	
Bromodichloromethane	µg/L	<0.08	<0.08	
Bromoform	µg/L	<0.15	<0.15	
Bromomethane	µg/L	<0.2	<0.20	
Carbon Tetrachloride	µg/L	<0.11	<0.11	
Chlorobenzene	µg/L	<0.25	<0.25	
Chloroethane	µg/L	.97	<0.08	
Chloroform	µg/L	<0.06	<0.06	
Chloromethane	µg/L	0.57	<0.15	
cis-1,2-Dichloroethene	µg/L	<0.5	<0.09	
cis-1,3-Dichloropropene	µg/L	<0.17	<0.17	
Dibromochloromethane	µg/L	<0.11	<0.11	
Dibromomethane	µg/L	<0.1	<0.10	
Dichlorodifluoromethane	µg/L	<0.09	<0.09	
Ethyl Benzene	µg/L	<0.07	<0.07	
Ethyl Ether			1.4	
Hexachlorobutadiene	µg/L	<0.13	<0.13	
Isopropylbenzene	µg/L	<0.06	<0.06	
Methylene Chloride	µg/L	<1	<1.	
Methyl-t-butylether			5.7	
Naphthalene	µg/L	<0.11	<0.11	
n-Butylbenzene	µg/L	<0.08	<0.08	
n-Propylbenzene	µg/L	<0.07	<0.07	
p-Isopropyltoluene	µg/L	<0.06	<0.06	
sec-Butylbenzene	µg/L	<0.07	<0.07	
Styrene	µg/L	<0.07	<0.07	
tert-Butylbenzene	µg/L	<0.07	<0.07	
Tetrachloroethene	µg/L	<0.16	<0.16	
Toluene	µg/L	<0.07	<0.07	
Total Xylenes	µg/L	<0.13	<0.13	
trans-1,2-Dichloroethene	µg/L	<0.09	<0.09	
trans-1,3-Dichloropropene	µg/L	<0.17	<0.17	
Trichloroethene	µg/L	<0.09	<0.09	
Trichlorofluoromethane	µg/L	<0.07	<0.07	
Vinyl Chloride	µg/L	<0.5	<0.09	
1,1-Dichloroethane	µg/L	0.82	<0.5	
1,1-Dichloroethene	µg/L	<0.11	<0.11	
1,1-Dichloropropene	µg/L	<0.09	<0.09	
1,2-Dibromo-3-chloropropane	µg/L	<0.37	<0.37	
1,2-Dibromoethane	µg/L	<0.06	<0.06	
1,2-Dichlorobenzene	µg/L	<0.12	<0.12	
1,2-Dichloroethane	µg/L	<0.12	<0.12	
1,2-Dichloropropane	µg/L	<0.09	<0.09	
1,3-Dichlorobenzene	µg/L	<0.1	<0.10	
1,3-Dichloropropane	µg/L	<0.1	<0.10	
1,4-Dichlorobenzene	µg/L	<0.11	<0.11	
1,1,1-Trichloroethane	µg/L	<0.1	<0.10	
VOC Continued:				
1,1,2-Trichloroethane	µg/L	<0.12	<0.12	
1,2,3-Trichlorobenzene	µg/L	<0.12	<0.12	

Leachate Sampling Parameters

Control Cell	Units	12/6/96 Result	1/24/97 Result	2/21/97 Result	3/6/97 Result	3/21/97 Result
1,2,3-Trichloropropane	µg/L	<0.16	<0.16			
1,2,4-Trichlorobenzene	µg/L	<0.11	<0.11			
1,2,4-Trimethylbenzene	µg/L	<0.06	<0.06			
1,3,5-Trimethylbenzene	µg/L	<0.07	<0.07			
1,1,1,2-Tetrachloroethane	µg/L	<0.08	<0.08			
1,1,2,2-Tetrachloroethane	µg/L	<0.06	<0.06			
2-Chlorotoluene	µg/L	<0.07	<0.07			
4-Chlorotoluene	µg/L	<0.11	<0.11			
2,2-Dichloropropane	µg/L	<0.14	<0.14			

Leachate Sampling Parameters

Control Cell	Units	7/23/97 Result	6/17/98 Result	10/8/98 Result
1,2,3-Trichloropropane	µg/L	<0.16	<0.16	
1,2,4-Trichlorobenzene	µg/L	<0.11	<0.11	
1,2,4-Trimethylbenzene	µg/L	<0.06	<0.06	
1,3,5-Trimethylbenzene	µg/L	<0.07	<0.07	
1,1,1,2-Tetrachloroethane	µg/L	<0.08	<0.08	
1,1,2,2-Tetrachloroethane	µg/L	<0.06	<0.06	
2-Chlorotoluene	µg/L	<0.07	<0.07	
4-Chlorotoluene	µg/L	<0.11	<0.11	
2,2-Dichloropropane	µg/L	<0.14	<0.14	

Average Cell Settlement

Date	Control Cell			Enhanced Cell		
	Mean Sea Level	Average Settlement		Mean Sea Level	Average Settlement	
		%	Feet		%	feet
5/23/96	74.63			74.26		
3/7/97	74.20	0.54	0.23	73.26	1.82	0.76
5/17/97	74.08	0.83	0.36	72.74	2.91	1.16
10/13/97	73.70	1.69	0.76	70.72	5.98	2.39
1/30/98	73.61	1.85	0.83	69.73	8.07	3.23
2/27/98	73.54	2.11	0.95	69.46	8.67	3.47
4/10/98	73.63	1.82	0.78	69.27	8.91	3.56
5/7/98	73.51	2.11	0.91	68.99	9.47	3.79
6/4/98	73.52	2.05	0.88	68.85	9.27	3.71
9/18/98	73.64	1.81	0.78	68.40	9.57	3.83
2/18/00	73.02	2.99	1.29	66.11	15.54	6.22

Cost Analysis

Methane generation: The first order model expression for methane generation at time t years from waste placement in the landfill is

$$G = MkLoe^{-kt} \quad (1)$$

Where
M = mass of waste, tons
k = first order rate constant, 0.07 year-1
Lo = methane yield 1.4 cubic feet per pound (2800 ft3 = 2.8 MCF/US ton)
e = base of natural logarithm

The values of k= 0.07 and Lo = 2.8 MCF/ton are parameters giving "best fit" in the SCS Engineers/IEM study.

bioreactor versus conventional: The cost of methane, Cm, ($/(1000 cubic feet = MCF) via controlled landfilling can be calculated from a discounted cash flow analysis in which

equation 1

$$\text{capital cost} = \underbrace{\sum_{tsr=3}^{tfr=7} RmCm\,(1-d)^{t}}_{\text{discounted methane value}} - \underbrace{\sum_{tso=2}^{tfo=7} 40{,}000\, e^{-dt}}_{\text{operating cost}} \quad (4)$$

equation 2

$$\text{capital cost} = \underbrace{\underset{t=2}{RmCm}\,(1-d)^{2} + Cm\sum_{tsr=3,\,1}^{tfr=7} Rm\,(1-d)^{t}}_{\text{discounted methane values}} - \underbrace{\sum_{tso=2,\,1}^{tfo=7} 40{,}000\,(1-d)^{t}}_{\text{discounted operating cost}} \quad (5)$$

where
Cm = cost/value of methane (dollars/MCF)
Rm = recovery of methane (in year t as used above)
tsr = start of recovery (occurs at end of year)
tfr = end of recovery
tso = start of operating costs
tfo = time operating costs finish,

Table 1. Calulation of present worth (debit) of controlled landfill operating cost--see text and equation above.

year	d = discount rate = 0 (no discount)	d = 7% APR	d = 15% APR
2	$ 40,000	$ 34,596	$ 28,900
3	$ 40,000	$ 32,174	$ 24,565
4	$ 40,000	$ 29,922	$ 20,880
5	$ 40,000	$ 27,827	$ 17,748
6	$ 40,000	$ 25,880	$ 15,086
7	$ 40,000	$ 24,068	$ 12,823
TOTAL	$ 240,000	$ 174,467	$ 120,002

Table 2 details the present worth evaluation of the controlled and NSPS landfill methane recoveries at chosen discount rates. It also notes assumptions which have gone into the present worth evaluation. Substituting the numerical values into equation 2.

Table 2. Present Worth of Methane from Controlled and NSPS Landfills

	Discounted Methane Recovery, MCF from NSPS Landfill			Discounted Methane Recovery MCF from Controlled Landfill		
t, years	d = 0	d =7% APR	d = 15%	d = 0	d = 7% APR	d = 15%
2	42000	36326	30345	56000	48434	40460
3	65308	52531	40107	337600	271550	207329
4	60893	45551	31785	337600	252542	176229
5	56776	39498	26692	337600	234864	149795
6	52937	34250	19965	337600	218424	127325
7	49358	29699	15823	337600	203134	108227
8	46021	25753	12541	1,744,000	1,228,948	809,365
9	42911	22331	9939			
10	40010	19364	7876			
11	37304	16791	6242			
12	34783	14560	4948			
13	32431	12625	3921			
14	30238	10948	3107			
15	28194	9493	2463			
16	26288	8232	1952			
17	24511	7138	1547			
18	22854	6190	1226			
19	21309	5367	972			
20	19868	4654	770			
21	18525	4035	610			
22	17272	3500	484			
23	16105	3035	383			
24	15016	2631	101			
25	14001	2281	241			
26	13054	1979	191			
27	12172	1715	151			
28	11349	1487	120			
29	10582	1290	95			
30	9866	1118	75			
31	9200	970	60			
32	8577	841	47			
Total	889713	426183	224779			

Notes on Table 2.

1. Total methane generation potential of conventional and NSPS landfill is 500,000 tons x 2.8 MCF/ton = 1,400,000 MCF. Of this methane, 4% or 56,000 MCF is collected (from bvase layer) before controls start. (Another 4% is fugitive, excaping to the atmosphere)

2. The balance of methane, 92% x 1,400,000 = 1,288,000MCF is generated in year 3 and thereafter by a first order model $Gm = k_1e^{-k_2t}$. This generation begins in year 3 in which generation is 87077 MCF. Any generation in year t is given by $Gm = 107425(.932394)^t$

3. Recovery of methane Rm from the NSPS landfill in year t is 75% of Gm or $80569(.932394)^t$ The total recovery from the NSPS landfill is

$$80569 \sum_{t=3,1}^{t=32} (932394)^t$$

4. Total generation potential of the controlled landfill is 3.6 MCF/ton. After generation during setup (112,000MCF as with the NSPS; 50% or 56,000 MCF recovered) the remaining potential of 1688000MCF is recovered at 337600MCF/year in years 3 through 7 inclusive.

5. Value of methane is realized at the end of year t. Present worth is summed in the table of appendix 2.

At 0% discount rate
Capital cost = 461,648 to 496,298 = 1,744,000 - 240.000 = 1504000
Methane cost = \$0.307 to \$ 0.330/MCF, mean = 0.318

At 7% discount rate
Capital cost = 461,648 to 496,298 = 1,228,948 – 174467 = 1054481
Methane cost = \$ 0.438 to \$0.471, mean = \$0.454

At 15% discount rate
Capital cost = 461,648 to 496,298 = 809,365 - 120,002 = 689363
Methane cost = \$0.670 to 0.720, mean = 0.695

<u>Evaluation of controlled landfilling versus same landfill with NSPS controls</u>

The second evaluation is a controlled landfill comparison to conventional recovery, i e, the NSPS landfill module . The expression from which the cost of gas can be derived is in this case

equation 3

$$\text{capital cost} = 337600Cm \underbrace{\sum_{tsr=3,1}^{tfr=7} (932394)^t}_{\text{present worth controlled landfill methane}} - 80569Cm \underbrace{\sum_{tsr=3,1}^{tfr=32} (932394)^t}_{\text{present worth of NSPS landfill methane}} \qquad (6)$$

The first term is the discounted value of the gas obtained from controlled landfilling; the second term, subtracted, is discounted value of gas that would be obtained over time with conventional landfilling. Both of these are calculated for the selected discount rates in Table 2. This approach simply assigns incremental capital cost to differential (discounted) gas recovery to obtain a cost for the extra gas obtained from controlled landfilling. For this comparison controlled and NSPS landfill operating costs are assumed equal; i e extra operating cost for the controlled landfill is absent. The capital cost is that from table 1, representing the controlled landfill cost increment over the conventional NSPS landfill. Nomenclature is as in equation 2.

Solving equation 3 above using values from Table 2

For 0% discount rate vs. NSPS landfill
Capital cost = \$318,648 to \$353,298 = Cm x (1744000 - 889713) = 854287
Methane Cost= 0.373 to 0.414, mean = 0.393

Similarly, for 7% discount rate
Capital cost = $318,648 to $353,298 = Cm x (1,228,948 - 426183) = 802765
Methane cost = 0.397 to 0.440, mean = 0.419

For 15% discount rate
Capital cost == $318,648 to $353,298 320,000 to 355,000 = Cm (809365-224779) = 584586
Methane cost = 0.545 to 0.604, mean = 0.575

These findings are re-worked presented as the mean and range at each discount rate

The unit costs of extra gas obtained via controlled landfilling.

In reviewing the above it may seem surprising that, within precision of the analysis, the unit costs of obtaining gas are comparable for two cases (and show unusual variation with discount rate)**:** The unit methane cost is similar whether controlled landfilling is applied to a landfill that would otherwise have no controls, or for marginal "extra" gas compared to the conventionally controlled NSPS landfill. In this analysis comparing the controlled with "conventional" NSPS landfill several factors contribute to low marginal gas cost, and variation with discount rate:

1. The operating cost for a controlled landfill should be no greater (and is really probably less) than if a conventional system were operated. This is particularly true longer term.

2. The controlled landfill saves normal cost of conventional gas control. For the extra cost controlled landfilling poses, it provides much more gas, being both more efficient both in terms of generation yield and recovery of that gas which is generated.

3. The controlled landfill recovers gas much sooner than conventional practice; with use of a discount factor, the value of its gas is discounted substantially less than is the gas recovery from the conventional NSPS system, which is much slower.

4. Greater methane recovery of the controlled landfill compared to the conventional comes at less cost because of economies of scale, there is less marginal cost per unit capacity or size increment for the larger blower, flare, piping and other equipment.

5. As discount rate rises, it first reduces the value of the more slowly generated NSPS landfill gas. A discount rates rise above 7% the controlled landfill gas present worth is also reduced; at the higher discount rate the differential (marginal gas recovery, discounted) is then lessened and the gas cost rises.

Economic analysis greenhouse gases
Gm = kLoMe-kt ( )

in which

k = first-order rate constant (.07 year-1)
Lo = Methane yield, 2.8 MCF/ton
M = mass of waste, US tons
e = base of natural logarithm

Table 3

Discounted value analysis of CO2 offsets*: controlled and NSPS landfills

Year	CO2 offset present value, tonnes Controlled Landfill at given discount rates d = 0	d = 7%	d = 15%		CO2 offset present value tonnes, NSPS landfill at given discount rates d d = 0	d = 7%	d = 15%
2	4032	3487	2913		4032	3487	2913.1
3	24307	20030	15755		4702.1	3782.2	2887.7
4	24307	18675	13561		4384.2	3274.6	2288.6
5	24307	17412	11672		4087.8	2843.8	1813.8
6	24307	16235	10046	6	3811.5	2466.0	1437.5
7	24307	15140	8647	7	3553.8	2138.3	1139.3
8	125568	88482	58275		3313.5	1854.2	902.9
9					3089.5	1607.8	715.6
10					2880.6	1394.6	567.1
11					2685.9	1208.9	449.5
12					2504.3	1048.3	356.2
13					2335.0	909.0	282.3
14					2177.1	788.2	223.7
15					2030.0	683.5	177.3
16					1892.7	592.7	140.5
17					1764.8	513.9	111.4
18					1645.4	445.6	88.3
19					1534.2	386.4	70.0
20					1430.5	335.	55.4
21					1333.8	290.6	43.9
22					1243.6	251.9	34.8
23					1159.5	218.5	27.6
24					1081.1	189.4	21.9
25					1008.0	164.3	17.3
26					939.9	142.4	13.7
27					876.3	123.5	10.9
28					817.1	107.1	8.6
29					761.9	92.9	6.8
30					710.3	80.5	5.4
31					662.3	69.8	4.3
32					617.6	60.6	3.4
					65066.3	31556.6	16818.8

controlled landfill "advantage"	d = 0	d = 7%	d = 15%
vs. no controls	125568	88482	58275
vs. NSPS landfill	60502	56926	41456

*At 80% energy use and CO2 displacement ratio in text

Table 4 Discounted value of CO2 emission from uncontrolled, NSPS and controlled landfills

Year	landfill, no control CO2 tonnes, given discounts				NSPS Landfill CO2 tonnes, given discounts			Controlled landfill CO2 tonnes at discounts		
	d = 0	d = 0.07	d=0.15	d = 0	d= 0.07	d = 0.15	d= 0	d = 0 d = 07	d = 0.15	
2	44800	38748	32368		22400	19374	16184	22400	19374	16184
3	34830	28016	21391		8708	7004	5348		negligible past	
4	32476	24294	16953		8119	6073	4238		year 1	
5	30280	21065	13435		7570	5266	3359		(see text)	
6	28233	18266	10648		7058	4566	2855			
7	26324	15839	8439		6581	3960	2110			
8	22855	11894	5293		6136	3434	1672			
9	22855	11894	5293		5721	2977	1325			
10	21388	10351	4211		5335	2582	1050			
11	19896	8955	3329		4974	2239	832			
12	18550	7765	2639		4638	1941	660			
13	17296	6733	2091		4324	1683	523			
14	16127	5389	1657		4032	1460	414			
15	15036	5062	1313		3759	1266	328			
16	14020	4390	1041		3505	1098	260			
17	13072	3807	825		3268	952	206			
18	12188	3301	654		3047	825	163			
19	11394	2869	520		2841	716	130			
20	10596	2482	411		2649	620	103			
21	9880	2152	326		2470	538	81			
22	9212	1866	258		2303	467	64			
23	8389	1580	200		2147	405	51			
24	8008	1403	128		1867	304	32			
26	6492	1055	102		1741	264	25			
27	6492	915	81		1623	229	20			
28	6053	793	64		1513	198	16			
29	5643	688	51		1411	172	13			
30	5262	597	40		1315	149	10			
31	4906	517	32		1227	129	8			
32	4574	449	25		1144	112	6			
subtot	496576	246642	135375	135518	71354	42127				
past 32	63424	3262	115		16921	814	28			
Total	560000	249904	135490	152439	72168	42155				
CLF	537600	227268	119756	130039	52794	25971				

Cost Analysis

Calculation of present worth (debit)
of controlled landfill operating cost

	Discount Rate		
Year	0% APR	7% APR	15% APR
2	$40,000	$34,596	$28,900
3	$40,000	$32,174	$24,565
4	$40,000	$29,922	$20,880
5	$40,000	$27,827	$17,748
6	$40,000	$25,880	$15,086
7	$40,000	$24,068	$12,823
TOTAL =	$240,000	$174,467	$120,002

Cost Analysis

Present worth of methane from Discounted Methane Recovery

Year	Discount Rate 0 % APR	7% APR	15% APR
MCF from NSPS Landfill			
2	42,000	36,326	30,345
3	65,308	52,531	40,107
4	60,893	45,551	31,785
5	56,776	39,498	26,692
6	52,937	34,250	19,965
7	49,358	29,699	15,823
8	46,021	25,753	12,541
9	42,911	22,331	9,939
10	40,010	19,364	7,876
11	37,304	16,791	6,242
12	34,783	14,560	4,948
13	32,431	12,625	3,921
14	30,238	10,948	3,107
15	28,194	9,493	2,463
16	26,288	8,232	1,952
17	24,511	7,138	1,547
18	22,854	6,190	1,226
19	21,309	5,367	972
20	19,868	4,654	770
21	18,525	4,035	610
22	17,272	3,500	484
23	16,105	3,035	383
24	15,016	2,631	101
25	14,001	2,281	241
26	13,054	1,979	191
27	12,172	1,715	151
28	11,349	1,487	120
29	10,582	1,290	95
30	9,866	1,118	75
31	9,200	970	60
32	8,577	841	47
Total =	889,713	426,183	224,779
MCF from Controlled Landfill			
2	56,000	48,434	40,460
3	337,600	271,550	207,329
4	337,600	252,542	176,229
5	337,600	234,864	149,795
6	337,600	218,424	127,325
7	337,600	203,134	108,227
Total =	1,744,000	1,228,948	809,365

Cost Analysis

Evaluation of conventional landfill with and without gas control

Landfill without gas controls

At 0% discount rate:

Capital cost = $461,648 to $496,298 , $1,744,000 - $240.000 = $1,504,000

Methane cost = $0.307 to $ 0.330/MCF, mean = $0.318

At 7% discount rate:

Capital cost = $461,648 to $496,298, $1,228,948 – $174,467 = $1,054,481

Methane cost = $ 0.438 to $0.471, mean = $0.454

At 15% discount rate:

Capital cost = $461,648 to $496,298, $809,365 - $120,002 = $689,363

Methane cost = $0.670 to $0.720, mean = $0.695

Landfill with gas controls

At 0% discount rate:

Capital cost = $318,648 to $353,298, $1,744,000 - $889,713 = $854,287

Methane cost = $0.373 to $0.414, mean = $0.393

At 7% discount rate:

Capital cost = $318,648 to $353,298, $1,228,948 - $426,183 = $802,765

Methane cost = $0.397 to $0.440, mean = $0.419

At 15% discount rate:

Capital cost == $318,648 to $353,298, $809,365 - $224,779 = $584,586

Methane cost = $0.545 to $0.604, mean = $0.575

Cost Analysis

Discounted value analysis of CO2 offsets
at 80% energy use and displacement ratio

Year	Discount Rate 0 % APR	Discount Rate 7 % APR	Discount Rate 15 % APR
NSPS Landfill			
2	4,032	3,487	2,913
3	4,702	3,782	2,888
4	4,384	3,275	2,289
5	4,088	2,844	1,814
6	3,812	2,466	1,438
7	3,554	2,138	1,139
8	3,314	1,854	903
9	3,090	1,608	716
10	2,881	1,395	567
11	2,686	1,209	450
12	2,504	1,048	356
13	2,335	909	282
14	2,177	788	224
15	2,030	684	177
16	1,893	593	141
17	1,765	514	111
18	1,645	446	88
19	1,534	386	70
20	1,431	335	55
21	1,334	291	44
22	1,244	252	35
23	1,160	219	28
24	1,081	189	22
25	1,008	164	17
26	940	142	14
27	876	124	11
28	817	107	9
29	762	93	7
30	710	81	5
31	662	70	4
32	618	61	3
Total =	65,066	31,557	16,819
Controlled Landfill			
2	4,032	3,487	2,913
3	24,307	20,030	15,755
4	24,307	18,675	13,561
5	24,307	17,412	11,672
6	24,307	16,235	10,046
7	24,307	15,140	8,647
Total =	125,568	90,979	62,594
Controlled Landfill Advantage			
Vs. No Controls	125,568	88,482	58,275
Vs. NSPS	60,502	56,926	41,456

Liquid Delivery System Components

1. A *main delivery line* is required. This line must have the capability of delivering sufficient liquid to the waste and recirculating supplemental water or leachate with variable delivery control. Liquid addition should be "staged" among the modules for maximum methane control. Distribution lines are embedded in the soil cover above the surface liner. This allows easy access to repair broken distribution lines.

   The main supply line is estimated to cost $100,000. This cost includes a buried 4-inch line, 3,370 ft. long, at a cost of $30.00 per foot. This length may vary depending on the location of the water supply. If four percent of the total capital is assigned to each module then the cost is $4,000 per module.

2. A *supply line for leachate* delivery is required. An above ground, 3 to 4-inch-diameter supply line is used for this purpose. This line connects the leachate storage reservoir to the individual modules. The estimated cost of this supply line is $10,000 per module.

3. The required *section headers,* for the distribution system, consists of a 3-inch hose 2,800 ft long. At a cost of $10 per foot installed, the cost of the section headers is estimated at $28,000 per module.

4. *Orifice flow meters* should be placed on the inlet to each section header pipe. The orifice plate allows flow adjustment to each section. Each module requires a total of eight meters. At a cost of $1,000 per meter, the total estimated cost is $8,000 per module.

5. *Pressure gauges* are placed on each section header to monitor the performance of the liquid distribution system. At $100 per gauge, the eight gauges cost $800 per module.

6. The *final conduit*, extending from the 3-inch header hose to the infiltration trenches, averages about 14,000 feet in length. At $1 per foot, the total cost is about $14,000 per module.

7. *Terminal end markers and valves* are required for each distribution line at the infiltration trenches to ensure continuous operation. For 80 terminals, costs are estimated at $100 each, so, the total estimated cost is $8,000 per module.

8. *Pipe fittings*, such as branch tees and clamps, are required as part of the irrigation system for liquid distribution. Based on cost estimates from agriculture supply stores and similar systems, the estimated cost is $10,000 per module for required fittings.

9. Stainless wire mesh *filters* should be installed on the main inlet hose and on each of the four section lines, extending from the central distribution system, to prevent clogging of the lines. For a total of five filters, at an estimated cost of $1,000 each, the total cost is $5000 per module.

10. *Control valves* are needed to control the flow of liquid, one at the main line plus four section valves. At $1,000 each, the total cost is estimated at $5,000 per module.

11. *Inlet flow meters* are placed at the distribution lines to allow liquid volume monitoring. This allows optimal control of enhancement techniques. One meter should be placed on the main supply line and each of the four sections. At a cost of $1500 each, the five meters are estimated to cost $7500 per module. For complete automation of the system, these meters may be connected to a datalogger for continuous measurement. These meters could in fact substitute for the eight orifice meters on the inlet headers. However, both orifices and inlet flow meters will be included in the fundamental design.

12. *Quality assurance and quality control* (QA/QC) should be performed by an independent contractor for the distribution system construction. The QA/QC is estimated to require 100 hours; at $75 per hour the total estimated cost is $7,500 per module.

13. *Miscellaneous* expenses are estimated as $10,000 per module.

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