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Landfill gas characterization and leachate removal at the Alachua County Southwest Landfill, Alachua County, Florida through utilization of a mechanical gas collection system.

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LANDFILL GAS CHARACTERIZATION AND LEACHATE REMOVAL AT THE ALACHUA COUNTY SOUTHWEST LANDFILL, ALACHUA COUNTY, FLORIDA THROUGH UTILIZATION OF A MECHANICAL GAS COLLECTION SYSTEM

By

KURT R. GIES, P.E.

A NON-THESIS PROJECT PRESENTED TO THE DEPARTMENT OF
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Dedicated to my family, Peggy, Cory, Magic and Taylor?. Without your love and support, this would have been meaningless. Thanks for always making me smile.

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LANDFILL GAS CHARACTERIZATION AND LEACHATE REMOVAL AT THE ALACHUA COUNTY SOUTHWEST LANDFILL, ALACHUA COUNTY, FLORIDA THROUGH UTILIZATION OF A MECHANICAL GAS COLLECTION SYSTEM

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Kurt R. Gies

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Chairman: Dr. W. Lamar Miller
Major Department: Environmental Engineering Sciences

In November 1992, a landfill gas collection system for the Alachua County Southwest Landfill was activated and set so that it was collecting gas from all the wells in a 30-acre area (operational from 1972 to 1985), and all the wells from an 11-acre area (operational from 1985 to 1988) at a flow rate in excess of 1,000 scfm. In February 1993, an analysis of the system commenced in an effort to optimize the flow and the quality of the extracted gas. Additionally, an attempt to determine the quantity of gas that can be expected over the next several years was made. Samples of gas were collected on the downstream side of the system's centrifugal blowers. Analysis of the gas components for CH_4, CO_2, N_2, and O_2 concentrations were conducted. Results indicated that the 30-acre area and the 11-acre areas were producing 264 scfm of methane. Based on

an average half-life of 14 years, the Scholl Canyon Landfill Gas Kinetic Model predicted the total flow from these two areas would average 116 scfm of CH_4 until the year 2000.

The production of gas from a 27-acre operating cell also was examined. In determining the amount that can be extracted, every effort was made to use the existing systems, while at the same time providing the least amount of disruption of the daily landfill operations. By connecting to the active cell leachate collection system clean-out line, 286 scfm of methane was captured from the operating cell. Based on the data from this study and other studies at this site, the Scholl Canyon model predicts a half-life of 5 years. The half-life was reduced because this area had been wetted.

Finally, an examination of the feasibility of using a landfill gas collection system to remove ponded leachate from degraded waste was conducted. It is predicted that 900 gal/day of moisture can be removed based on a temperature difference of 40°F and flow of 1000 scfm. The method used for this study estimated that leachate was removed at a rate of 8,228 gallons/day. Because of this method, various assumptons that were made in determining this rate resulted in an over estimation of the volume removed. Leachate was removed from the waste, but the quantity needs to better defined.

CHAPTER 1
INTRODUCTION

Background

Throughout history, land disposal of solid waste has been the primary means for processing this waste. Man would generate products and discard the waste, usually with little thought to the impact. Franklin Associates (1988) estimated that approximately 80 percent of the waste produced in the United States was deposited in landfills in 1987. Most of the public thinks that once the waste is thrown away that this is the end of the process. This is far from the truth.

When waste is deposited, the organic portion begins to decompose. Initially, refuse placed into the landfill contains trapped air. Aerobic bacteria begin to decompose the waste until the oxygen has been consumed. The anaerobic bacteria then begin to develop. In the anaerobic environment, the organic fraction of the waste is broken down into methane, carbon dioxide and water. If for any reason oxygen is reintroduced in the waste, the anaerobic bacteria begin to die, thus impeding degradation and methane production.

Gas production in landfills is an area of increasing environmental concern. Uncontrolled emission or migration

of the gas poses a potential fire and explosion hazard, can acidify the groundwater, and can create potentially harmful and foul smelling emissions from the landfill. If landfill gases are allowed to migrate off-site, methane may accumulate in subsurface structures such as manholes or basements. An ignition source is all that is then needed to create an explosion. If very large quantities of air are introduced into the waste, subsurface combustion of the buried waste may occur.

The first major investigations into the management of landfill gas occurred during the energy crisis of the 1970's. It was concluded that the methane content of landfill gas was sufficient to consider the investment of a collection and treatment system to convert the gas to a usable energy alternative. However, very few sites had these systems installed because of the high initial capital investment required.

The recent trend towards environmental awareness and concern has rekindled the landfill gas collection initiatives. U.S. Environmental Protection Agency regulations now require landfill operators to control landfill gases and monitor to ensure there is no migration off-site. Now instead of collecting the gas for profit, the emphasis is on collecting the gas to protect the environment.

There are many techniques for controlling landfill gas migration, but the primary means is the use of an active gas collection system which is connected to some form of gas conversion system. At the Alachua County Southwest Landfill (ACSWLF) where this study was conducted, gas is collected and flared.

Water generated in the decomposition process, along with precipitation that falls on the waste, percolates down through the waste. This liquid is known as leachate. If the landfill is located in area of soils that are highly permeable, leachate can migrate off-site into underlying aquifers. Leachate migration is considered by many to be the major environmental concern associated with landfills (Pohland, 1986). Regulations now govern the monitoring and management of leachate. New landfills are required to be constructed with a liner and have a leachate collection and treatment system. Unfortunately, little has been done to determine how to manage the problem of ponded leachate in landfills that have no liner and leachate collection system.

Objectives

The objectives for this study are as follows:

1) Determination of the average decay rates for the biodegradable portion of waste deposited in the ACSWLF. To be determine these values, optimization of the gas collection system's configuration, so that the gas quality

and quantity being collected was maximized needed to be accomplished. Based on the results of the Scholl Canyon Kinetic Gas Model and a comparison of the actual quantity being collected, the half-lives of the waste were predicted. In one of the three areas where the half-life study was conducted, Wet Cell technolgy was simultaneously being examineded by others. As a result, a major portion of this area was wetted. Additionally, it was uncapped. The Wet Cell technology theory anticipates that the half-life of the waste will be dramaticaly decreased.

From the above results, an estimate of the quantity of gas that can be anticipated over the next several years was made. Alachua County can then decide which is the most economical energy conversion process for this site.

2) The second objective of this study was to examine whether a landfill gas collection system can be used as a means of removing ponded leachate from previously deposited waste.

CHAPTER 2
LITERATURE REVIEW

Landfill Gas and Leachate Migration Hazards

The literature has documented numerous instances of problems created by leachate and gas migration from landfills into the surrounding environment. Although the extent of the problem is difficult to quantify, problems associated with these landfill by-products were documented as early as 1932 (Pohland, 1986).

The gas produced from landfills typically consists of 60 percent methane and 40 percent carbon dioxide, and results primarily from waste decomposition. Additionally, landfill gas does contain minor concentrations of non-methane organic compounds (NMOC). The U.S. Environmental Protection Agency has estimated that approximately 10.5 million Mg of methane and 225,000 Mg of NMOC's are emitted from landfills each year (Reinhart et al., 1992). These landfill emissions also pose potential problems when they are allowed to migrate off-site. Besides being malodorous and corrosive, landfill gases can be a fire or explosion hazard. Methane has been known to migrate into subsurface structures such as manholes, catch basins, and residential and commercial basements. If the concentration of methane

is diluted to 5 to 15 percent by volume of air, explosions can occur. Additional potential problems caused by migrating landfill gases include tropospheric ozone production from chemical reactions of the NMOCs and methane. Cancer and other health related effects have been documented from exposure to NMOCs (US EPA, 1991). Methane also is considered to be a potent greenhouse gas (Reinhart et al., 1992).

In 1975, the U.S. EPA reviewed five municipal waste disposal sites where leachate migration contaminated the groundwater and caused pollution of local wells. As a result, the wells had to be abandoned and the water supply replaced (Walsh et al., 1979). In 1977, it was reported to Congress that out of 42 municipal and 18 industrial sites surveyed, five of the municipal and 14 of the industrial disposal sites had added toxic pollutants into the local water supply. It was reported (Shuster, 1976) that waste placed in an open dump operating over a creviced bedrock aquifer had leached. As a result, seven residential wells were contaminated to the extent that they were declared unusable. BOD levels in three of the wells, caused by material leached from the dump, far exceeded that of raw sewage.

In response to the potential health and environmental risks created by off-site migration of landfill gases and

leachate, the U.S. EPA has taken steps to limit the damage through the permitting process.

Gas Production

Decomposition Process

When waste is placed into a landfill, a series of complex physical, chemical and biological processes take place. Methane gas is produced during a specific phase of the biological processes. These biological processes involve the conversion of the organic portion of wastes into cellular and partially decomposed matter and gases. The chemical processes involve the conversion of materials in the waste by hydrolysis, sorption-desorption, dissolution-precipitation or ion exchange resulting in greater mobility and changed characteristics of the waste components. Finally, the physical processes involve transport of waste components by leachate as it flows through the waste (Ham et al., 1979).

The biological portion of the decomposition process involves five identifiable phases, each with its own characteristic products and effects, i.e. leachate and gas production. Pohland identified these phases and was able to couple them with the landfill age. These phases were Initial Adjustment, Transition, Acid Formation, Methane Formation, and Final Maturation (Pohland, 1986). Each of

these phases often takes place at the same time in a full-scale, active landfill as fresh municipal solid waste (MSW) is constantly being placed.

Phase I. The first phase of MSW decomposition is called the Initial Adjustment phase. This occurs when the waste is placed in the landfill and moisture begins to accumulate. The MSW then is covered and the oxygen trapped within the waste supports an aerobic biological environment. During this phase, oxygen, nitrates and soluble sugars are being consumed by aerobic and facultative anaerobic bacteria. Very little gas is being produced and leachate production is primarily a result of storm water runoff from the waste.

Phase II. The second phase, the Transition phase, begins when the field capacity of the waste is reached and leachate starts to flow through the landfill. The field capacity of MSW is the point where the moisture held by the waste is overcome by gravity and begins to drain. During this phase, the biological environment begins to change from aerobic to anaerobic.

During the aerobic portion of this phase, oxygen is consumed and converted into carbon dioxide and water. The carbon dioxide content has been reported to be as high as 90 percent in this phase (Ham et al., 1979). Part of the carbon dioxide dissolves into the surrounding leachate and causes a drop in the pH of the surrounding environment.

Aerobic decomposition is considered to be relatively rapid when compared to the length of the anaerobic phase. Temperatures range from 35° to 40°C.

In the anaerobic portion of this phase, oxygen is depleted so the primary electron acceptor shifts from oxygen to the nitrates and sulfates. Reducing conditions are established. The production of carboxylic acids and a lower pH level (pH=6.7) in the leachate begins to be observed (Pohland, 1986).

Phase III. The third phase is called the Acid Formation phase. Volatile fatty acids become predominant and the pH has been observed to drop as low as 4.7 (Pohland, 1986). The acidic conditions result in dissolving inorganics such as metals into the leachate. Additionally, nutrients such as nitrogen and phosphorous are released and become available for biological growth. Some decomposition of cellulose and hemicellulose will be observed (Barlaz et al., 1990). Carbon dioxide is still the predominant gas, but some hydrogen formation may be noted.

Phase IV. After the readily available oxygen has been depleted and the reducing conditions established, the fourth phase, Methane Formation, begins. Strictly anaerobic micro-organisms become dominant. There are three types of bacteria working to form methane: 1) fermentative organisms, 2) acetogenic organisms and 3) methanogenic organisms.

These bacteria are efficient, but work relatively slowly in forming methane, carbon dioxide and water.

The methanogenic decomposition process produces the majority of the landfill gas. Figure 2-1 (Barlaz et al., 1990) is a schematic of the process and shows how the microorganisms work together to convert organic MSW solids to gas. Biological polymers, cellulose, lipids and proteins, are acted upon by hydrolytic and fermentative organisms and the products are divided into three groups: 1) 76 percent of the by-products are alcohols and carboxylic acids (except acetate), 2) 20 percent is acetate and 3) 4 percent are converted to carbon dioxide and hydrogen. Acetogens act on group one and convert 68 percent of this group to acetate and 32 percent to group three. Group two, the acetates, are then converted to methane and carbon dioxide by the acetophilic methanogens and group three, the hydrogen and carbon dioxides, are converted to methane and water by the hydrogenophilic methanogens (Barlaz et al., 1990).

During this phase, the pH returns to neutral conditions, nutrients continue to be consumed and precipitation of metals progresses.

<u>Phase V.</u> The last phase is called the Final Maturation phase. Biological activity and gas production basically ceases as the organic constituents in the waste and leachate required for production are exhausted. The natural

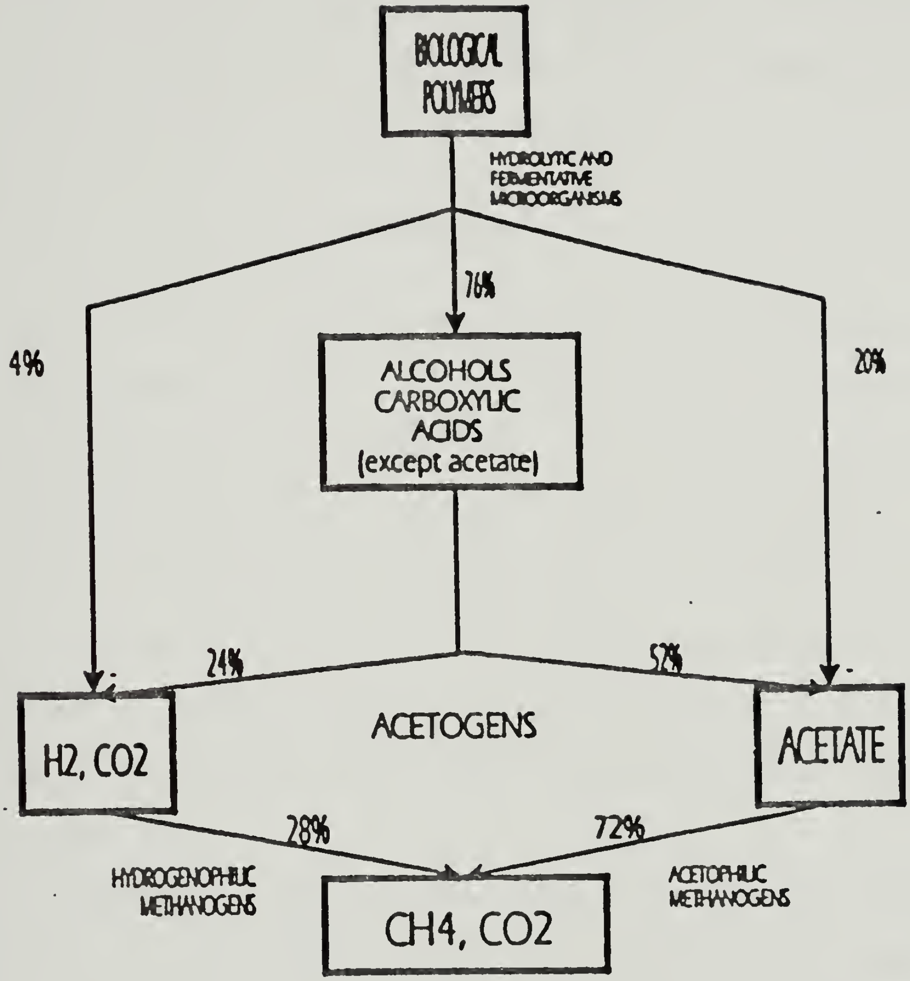

Figure 2-1: Typical Pathways for Methane Production from Polymeric Substrates (Barlaz et al., 1990)

conditions return and aerobic conditions slowly begin to predominate.

Table 2.1 is a summary of the chemical and physical indicators in leachate and Figure 2-2 is a summary of gas quality during each decomposition phase.

Factors Affecting Gas Production

Gas production from the decomposition of MSW can be affected by many factors. Variables such as the waste composition, moisture content of the MSW, particle size and compaction of the waste, buffer capacity, nutrients available, temperature and the phase of decomposition all have an impact on the rate and quality of landfill gas production (Pohland, 1986). The following is a general summary of the literature on the effects of each factor on gas production.

Waste Composition. The nature of the solid waste placed in a landfill is mainly a function of the geographic location of the landfill and origin of the waste. The waste composition influences the gas production in terms of: 1) relative abundance of usable substrate, 2) presence of potential inhibitors and 3) formation of localized "micro environments" which could be separated from the system gas transport phases. A characterization from a composition analysis of typical MSW placed into landfills active in the 1980's is shown in Figure 2-3 (Franklin Assoc., 1986). The

Table 2.1: Landfill Leachate And Gas Concentration Ranges Encountered In The Literature AndTheir Relative Significance To The Degree Of Landfill Stabilization (Pohland. 1986)

Leachate or Gas Constituent	**Transition Phase**	**Acid Formation Phase**	**Methane Fermentation Phase**	**Final Maturation Phase**
Biochemical Oxygen Demand (BOD_5)	100-10,900 Influence of dilution and aerobic solubilization of waste organics	1,000-57,700 Accumulation of biodegradable organic acids methanogenic lag	600-3,400 Conversion of biodegradabl e organics to gaseous end products	4-120 Influence of high-molecular weight organic residuals (
pH	6.7	4.7-7.7 Low due to volatile acid accumulation	6.3-8.8 Inc, volatile acid removal and bicarbonate dissolution	7.1-8.8
Ammonia Nitrogen (NO_3^--N) mg/l	120-125	2-1,030 Increasing, nitrate reduction/prot breakdown	6-430 Decr, biological assimilation	6-430
Total Alkalinity mg/l as $CaCO_3$	200-2,500	140-9,650 Inc, volatile acid formation and bicarbonate dissolution	760-5,050 Dec, volatile acid removal	200-3,520

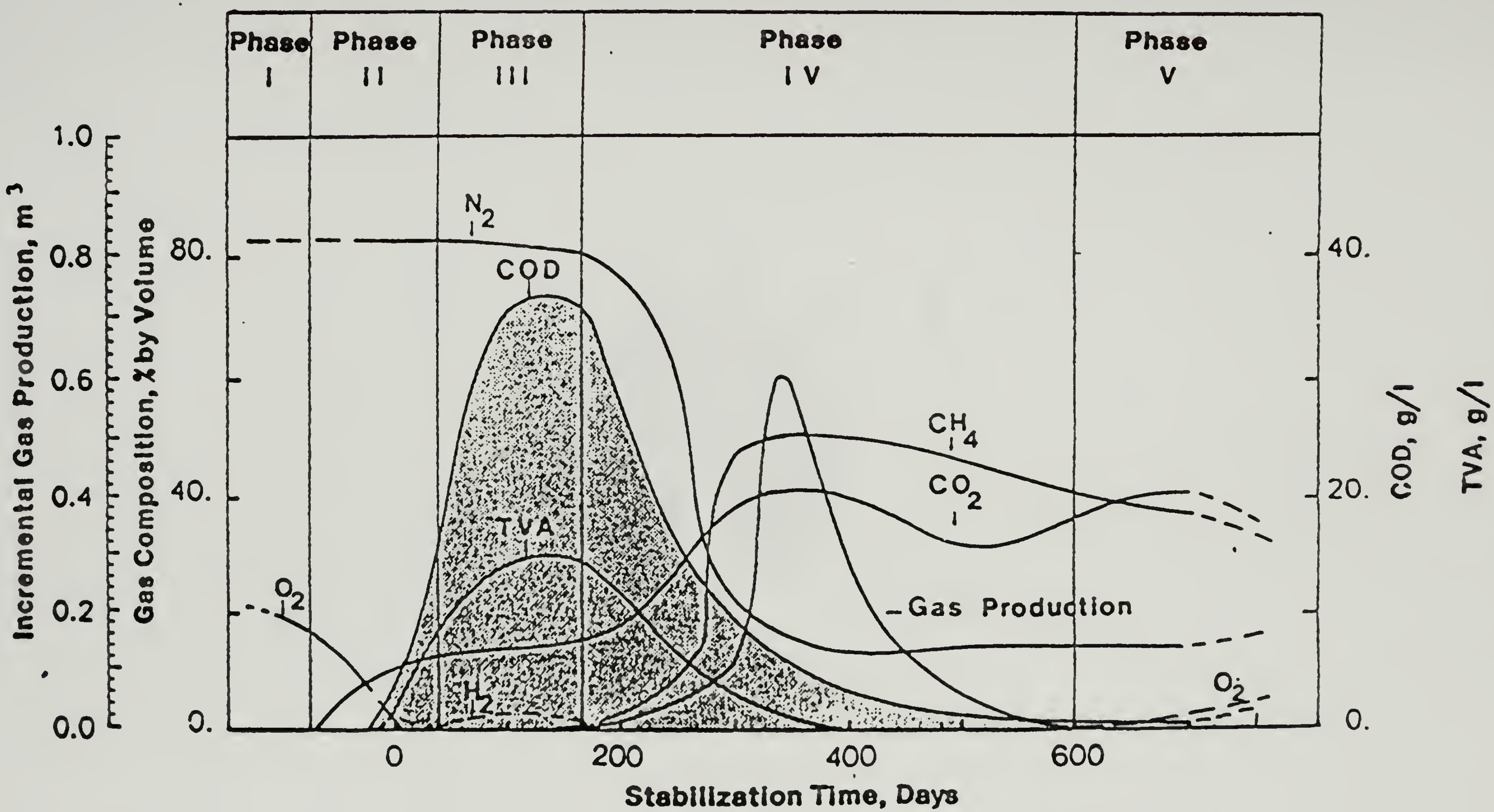

Figure 2-2: Changes in selected Indicator Parameters During the Phases of Landfill Stabilization (Pohland, 1986).

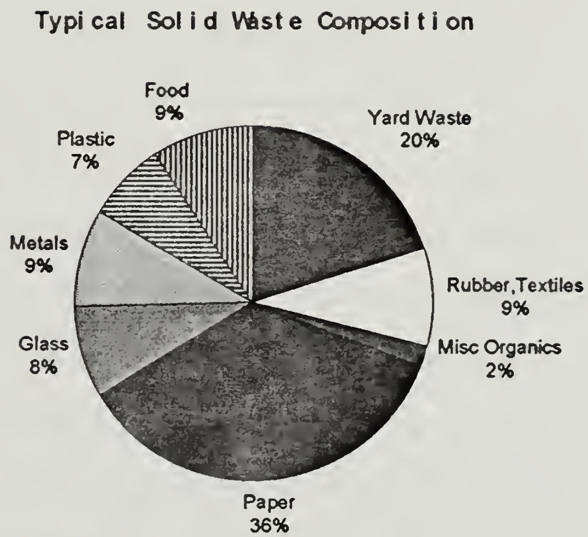

Figure 2-3: Typical MSW composition, 1986 estimate (EMCON, 1988)

largest portion is represented by paper products. Paper products are not considered as easily biodegradable as food and lawn waste, even though they still are included in the portion of the waste stream that is categorized as easily biodegradable (Ham et al., 1979). This represents 60 to 70 percent by weight of the MSW stream typically placed into landfills in 1985 (Franklin Assoc., 1986).

Moisture Content. The moisture content of MSW has been determined to greatly affect the rate of decomposition and gas production. Moisture provides the transport phase for the organic substrates and nutrients and is considered to play a vital role in establishing the anaerobic environment needed for methane production. Eliassen considered the optimum moisture content of MSW to be between 50 percent and 70 percent and 30 percent and 80 percent for fresh and older landfills, respectively (Eliassen, 1975). Chian and Dewalle found that a 75 percent moisture content or above was the best for the biodegradation process (Chian and Dewalle, 1979). Ham concluded that the optimum moisture content needed for increased methane generation was between 30 percent and 50 percent (Ham et al., 1979). Pohland concluded that methane production will continue to increase as moisture content increases to the 60 percent level with no significant increase or decrease in production rates thereafter (Pohland, 1986). The more recent literature

states that the biodegradation continues to increase up to 90 percent.

Current EPA guidelines call for the MSW to be "dry tombed." Essentially, the waste is kept as dry as possible by not allowing wet waste to be placed and by providing an impermeable cap on the cell once it is full. Therefore, the moisture content and gas production will be lower than anticipated in landfills that have been closed as these were normally never capped. The moisture content of the waste as received is generally in the 15 to 40 percent range, depending on the location, season, weather and waste composition (Tchobanoglous et al., 1993).

Size and Compaction. The size and compaction of MSW particles can contribute to the overall decomposition process. By shredding, the surface area available for biological use increases, thus allowing for greater gas production (DeWalle et al., 1978; Fungaroli, 1979). Barlaz and Pohland state that pilot studies have been inconclusive regarding the effect of particle size on methane production (Barlaz et al., 1990 and Pohland, 1986).

The extent to which MSW is compacted can have an adverse effect on the generation of gas. Greater compaction optimizes landfill space, but also decreases the permeability for moisture infiltration and gas flow-through. Without sufficient moisture, gas production and biodegradation rates will not be maximized. Present

landfill practice is to compact the waste to a high degree, 1100 lb/yd^3 (Miller et al., 1993). If shredding is done, the compaction rates can be even higher.

<u>Buffer Capacity.</u> The buffer capacity of MSW has an impact on the rate of methane production within a landfill. Buffer addition has been shown to increase the biological stabilization and gas production from MSW (Pohland, 1986). A buffer is reported to be needed to counteract the effects of the volatile fatty acids produced by acid-forming bacteria. Without a buffer, the pH of the MSW environment would decrease below the level favorable to methanogenesis (pH 6.6-7.4). Lowering the pH slows the biodegradation and gas production processes.

<u>Nutrients.</u> Nutrients are essential to microbial communities in MSW. In particular, bacteria use nitrogen and phosphorous to convert organic materials to methane and carbon dioxide. Full-scale municipal landfills contain the nutrients necessary to support the effective biological conversion of MSW, though studies have shown that phosphorous may become a limiting factor during the latter stages of biostabilization (Pohland, 1986).

<u>Temperature.</u> Temperature affects the production of gas in a landfill. The effects from temperature generally classify bacteria into three ranges: 1) thermophilic range, in which temperatures are found to be 45°C to 75°C; 2) mesophilic range, in which temperature are between 20°C to

50°C; 3) psychrophilic range in which the temperatures are less than 30°C (Tchobanoglous et al., 1993). Gas production rates appear to at an optimum in the 30°C to 35°C range (Ham et al., 1979).

Gas Yield Projections

Defining the ultimate gas production from MSW is important in determining the viability of certain gas recovery and conversion projects. The range of biodegradable matter in MSW and many combinations of the factors outlined above, result in complex systems with no simple equation to determine the rate of decay and rate of methane formation. Substances such as sugars and starches, i.e. food wastes, decompose more quickly than substances that contain cellulose, i.e. paper products. Wet, nutrient-rich wastes produce gas faster than dry, sterile waste. Even though many factors affect the overall equation, generation of landfill gas basically can be characterized by the following:

Organic Matter + H_2O + bacteria = stabilized waste + CH_4 + CO_2 + trace gases.

Based on this general relationship, the literature discusses several theoretical and empirical models available for formulating gas yields.

Theoretical Models

The mixed organic fraction of MSW has been characterized by many researchers and expressed as one empirical organic compound of the form

$$C_aH_bO_cN_dS_e.$$

where C, H, O, N and S represent the carbon, hydrogen, oxygen, nitrogen and sulfur fraction of the MSW, respectively. Table 2.2 are some of the results found in the literature. By using this simplified equation as a means of representing MSW, researchers have attempted to project the theoretical gas yield from MSW. One equation developed takes the organic composition and combines it with a theoretical amount of water and the proper bacterial conditions to produce a stoichiometrical quantity of methane, carbon dioxide, ammonia and hydrogen sulfide. In this process all the carbon is converted to either methane or carbon dioxide.

$$C_aH_bO_cN_dS_e+\left(n-\frac{a}{4}-\frac{c}{2}+\frac{3d}{4}+\frac{e}{2}\right)H_2O\Rightarrow\left(\frac{a}{2}+\frac{b}{8}-\frac{c}{4}-\frac{3d}{8}-\frac{e}{4}\right)CH_4+\left(\frac{a}{2}-\frac{b}{8}+\frac{c}{4}+\frac{3d}{8}+\frac{e}{4}\right)CO_2+dNH_3+eH_2S$$

(Ham et al., 1979).

Several results have been obtained based on the variability in characterizing the MSW. The data for ACSWLF indicates the theoretical amount of gas from this landfill would be 4.91 ft^3/lb of MSW total over the life of the waste (Manley, 1992). The composition of the gas would be

Table 2.2: Examples of MSW Chemical Formulas Applied to Theoretical Methane Yield Models (Pohland, 1986).

Waste Component	Chemical Formula
MSW (EMCON)	$C_{99}H_{149}O_{59}N$
MSW (Miller)	$C_{91}H_{153}O_{87}NP_2$
Paper, yard waste, wood	$C_{203}H_{334}O_{138}N$
Food Waste	$C_{16}H_{27}O_8N$
Cellulose	$C_6H_{10}O_5$

Table 2.3: Summary of the Theoretical Gas Yields from MSW Reported in the Literature (Pohland, 1986).

Source	Total Gas Yield (ft^3/lb)	Methane Yield (ft^3/lb)
MSW (Overall)	6.58	3.85
MSW (Overall)	6.74	3.37
MSW (Overall)	7.38	4.01
MSW (Overall)	7.23	3.69
Weighted Biodegradability	5.62	2.73
Weighted Biodegradability	3.05	1.44
Weighted Biodegradability	4.01	1.93
Weighted Biodegradability	1.93	0.96

47 percent methane and 53 percent carbon dioxide. Table 2.3 is a summary of some other values found in the literature.

Mathematical Models

There is very little evidence that the organic decomposition of MSW follows any standard order of decay. However, to mathematically model the actual conditions found in the field, researchers have developed equations which use zero- and first-order decay reactions (Ham et al., 1979).

The Scholl Canyon Kinetic Model (Schumacher, 1983) is one such model that has been developed and uses a first-order decay reaction as its foundation. This kinetic model is analogous to those used to describe oxygen uptake in dilute aqueous solutions by bacteria using soluble organic matter as the substrate. One example of this application is the reduction of biochemical oxygen demand (BOD) in a BOD bottle. Another is the deoxygenation term of the classical Streeter-Phelps equation used to describe the oxygen deficit from bacterial metabolism downstream from an input of waste into a river (Schumacher, 1983).

Leachate Production

Leachate, as defined by Tchobanoglous, is the liquid that has percolated through solid waste and has extracted dissolved or suspended materials. The leachate primarily comes from liquid that has entered the landfill from external sources, such as rainfall, surface runoff,

groundwater or from liquid produced from the waste decomposition process. The potential for leachate production can be examined by preparing a water balance on the landfill system. By adding up all the expected inputs of water and then subtracting out those quantities consumed in chemical reactions in the MSW, that which has escaped as water vapor, and that quantity which is held in the MSW as its field capacity, an estimated leachate-generation potential of the landfill can be calculated.

Water that enters the landfill from rainfall is the amount of actual rain that ultimately percolates through the cover layer. The Hydrologic Evaluation of Landfill Performance (HELP) model is one model that is widely used to estimate this quantity. Water that enters from the actual waste input into the cell varies as it is directly related to the type of waste, the source location and climate, the waterproof-type container it was kept in before delivery and how well the container worked. For estimating purposes, the moisture content of MSW entering a landfill is about 20 percent (Tchobanoglous et al., 1993). Another daily source of water is the cover material used. Again, this value will vary depending on the source of the material. Typical field capacity values for various materials used as daily cover range from 6 to 12 percent for sands, to 23 to 31 percent for clay loams (Tchobanoglous et al., 1993).

Water exiting the landfill is that quantity which exceeds the field capacity (FC) of MSW. The FC for landfills varies with the overburden weight in the cell and can be calculated by the following relationship:

$$FC = 0.6 - 0.55\left[\frac{W}{(10,000 + W)}\right]$$

where W is the overburden weight calculated at the midheight of the MSW in the cell (Tchobanoglous et al., 1993).

The amount of water consumed in the formation of landfill gas in the decomposition of rapidly degrading waste can be estimated. On a mass of water per pound of dry organic waste and an estimated organic makeup for the particular waste, this quantity can be calculated by use of the modified Buswell equation.

Landfill gas is usually 100 percent saturated with water vapor when it leaves the landfill (Tchobanoglous et al. 1993). Using this fact and incorporating the Ideal Gas Law, a mass of water per cubic foot of landfill gas can be calculated. A landfill gas collection system must take this into consideration in the design process, as there is a large amount of condensate from the gas as it is removed from the warm cell and transported to a cooler manifold system.

Leachate production for the ACSWLF has been studied (Townsend, 1992). Based on daily recorded information from the leachate collection system located at this site, a total of 7 million gallons was collected during 1992. The leachate quality also was monitored. Table 2.4 is a summary of the indicator parameter concentration ranges for various sources of leachate as found at ACSWLF.

Leachate Management

The management of leachate recently has become a major area of interest. Many state and local governments have placed tight requirements on landfills to monitor their leachate production, quantity and quality. Additionally, requirements to keep this potentially harmful liquid from escaping the boundaries of the landfill site and entering into the local groundwater supply have been developed. Various management options have been studied to deal with these requirements which include collecting and storing the leachate on site or removing and treating the leachate. Leachate recycling, evaporation, on-site biological treatment, and lime treatment followed by disposal with discharge to a wastewater treatment facility are all options being used by the landfill industry.

Table 2.4: Summary of Leachate Contaminant Concentration Ranges Found at the ACSWLF from October 1991 to September 1992 (Miller, 1992).

Analyte	Raw	Treated	Ponds	11-acre gas well
pH	6.50-6.89	8.80-10.02	7.18	7.25
Conductivity (umho/cm)	4230-7400	1370-2090	2620-2830	10100-22800
TDS (mg/l)	2030-2905	901-1704	1529-1768	6331-8526
COD (mg/l)	597-940	122-386	237-388	3570-4153
BOD (mg/l)	120-318	<2.0-15	-	-
Ammonia (mg-N/l)	111-298	44-151	41-99	705-709
Chloride (mg/l)	380-737	247-362	369-443	1297-1340
Alkalinity (mg CaCO3/l)	1575-2493	233-1155	900-1164	5125-8490

Gas Management

Flow in Porous Media

Darcy's Law. Darcy's Law is the basis for calculating fluid flow in porous media (Charbeneau et al., 1992). Darcy developed an expression balancing the pressure gradients and gravity forces that drive the flow and the viscous resistance to fluid motion. In porous media the small pore dimensions and the small fluid velocities dictate that subsurface flow is usually laminar, rather than turbulent. As a result, Darcy's Law expresses a linear relationship between the energy gradient, which causes the flow, and the flow velocity.

By experimentation, Darcy arrived at the following empirical law relating the total discharge, Q, across a filter bed to its area, A; water level change across the filter, $(z_1 - z_2)$; and filter thickness, L.

$$Q=K_hA(Z_1 -Z_2)/L$$

The constant K_h is called the hydraulic conductivity.

The hydraulic conductivity is perhaps the most important property of a porous medium. Values of K_h can be assigned to every point within a formation, which is referred to as the to the hydraulic conductivity field. If the value of K_h is the same at every point, then the field

is said to be homogeneous; otherwise, it is a heterogeneous field. If the hydraulic conductivity also has directional characteristics, the field is anisotropic. However, if the magnitude of K_h is independent of direction, then the field is isotropic. For engineering calculations at a particular site, it often is assumed that the hydraulic conductivity is independent of direction in the horizontal plane (Charbeneau et al., 1992).

It has been shown from detailed studies of porous media flow that the hydraulic conductivity of the medium is a function of both fluid and medium properties and saturation. The following is a general equation to determine the hydraulic conductivity:

$$K_h = k\rho_w g/\mu_w,$$

where k is the intrinsic permeability of the medium. The intrinsic permeability is assumed to be a function only of the porosity, pore size distribution, soil texture, structure and saturation. The intrinsic permeability is not a function of the invading fluid, so long as this fluid does not change the soil structure. The other parameters that appear in the above equation are the water density, ρ_w, dynamic viscosity, μ_w, and g, which is the gravitational constant. Density, ρ_w, depends only slightly on temperature

and pressure. On the other hand, the viscosity is sensitive to temperature variations and can be significant.

If the density of the fluid varies within the porous matrix, then the entire form of Darcy's Law must be modified. The most general form of Darcy's Law is

$$q = -(k/\mu_f)(\Delta p + \rho_f g k),$$

where q is the velocity or flow rate per unit area, Δp is the pressure gradient and k is the vertical upward unit vector.

There does not appear to be a lower limit to the range of applicability of Darcy's Law for aquifer materials. For large hydraulic gradients and velocities, there is ample evidence that the flow does depart from the linear relationships of Darcy's Law (Meinzer, 1942). At large flow rates, inertial effects become important, and the flow characteristics approach those of turbulent flow. Experiments have shown that these effects do not become important until the Reynolds number, N_R, reaches a value of about 1 to 10 where

$$N_R = q\rho_f d/\mu_f$$

and where d is the mean grain size. Laminar flow conditions are met under most field applications and it is generally

assumed that Darcy's Law applies throughout (Charbeneau et al., 1992).

For gas flow in porous media, it is assumed that Darcy's Law applies. Again, this implies that the driving force from pressure gradients and gravity is balanced by the viscous resistance force associated with the flow. Under most conditions, the force associated with pressure gradients is much larger than that due to gravity (as the density of air is so small), and Darcy's Law may be written in the approximate form

$$q = (k/\mu_f)\Delta p$$

(Charbeneau et al., 1992).

This equation is appropriate for horizontal flow and may usually be accepted in general for flow of gas in porous media. To express this in terms of head of water column, multiply this equation by the density of water and the gravitational constant, $\rho_w g$:

$$q = (k\rho_w g/\mu_f)\Delta p \ [L/T].$$

Continuity Equation. The continuity equation is a mathematical statement of the physical law of conservation of mass. Darcy's Law and the continuity equation, along with appropriate boundary and initial conditions, provide the mathematical framework to solve for the head and

velocity throughout a domain as a function of location and time. The continuity principle from fluid mechanics states the following for an arbitrary control volume:

> rate of mass accumulation within the volume + the net mass flux out of the volume = the rate of mass generation within the volume (Bird et al., 1960).

The analogy of groundwater flow to describe the distribution of pressure around venting wells has been used by Johnson et al. (1988). They determined for conditions of radial flow, the governing equation can be written as

$$\frac{1}{r}\left(\frac{\partial}{\partial r}\right)\left(r\frac{\partial P'}{\partial r}\right)=\left(\frac{\phi\mu}{kP_{atm}}\right)\frac{\partial P'}{\partial t},$$

where P' is the deviation of pressure from the reference pressure P_{atm}; k is soil permeability; μ is the vapor viscosity; ϕ is porosity and t is time. When this equation is solved with appropriate boundary conditions, with m as the thickness of the unconfined zone and r as the radial distance from the well to the point of interest,

$$P'=\frac{Q}{4\pi m(k/\mu)}W(u),$$

where W(u) is the well function of u and $u = r^2\phi\mu/4kP_{atm}t$. W(u) is a commonly tabulated function (Charbeneau et al., 1992).

For sandy soils (10 < k < 100 darcys), the above equation provides a pressure distribution approximation which attains steady state within a few hours (Charbeneau et al., 1992). Thus, it is appropriate to model pressure distributions using a steady-state solution to the governing flow equation. For the following set of boundary conditions: $P = P_w$ at $r = R_w$ and $P = P_{atm}$ at the ambient pressure at the radius of influence R_I.

The following solution to the steady-state equation for radial flow has been developed

$$P(r)^2 = P_w^2 + \left\{ \left(P_{atm}^2 - P_w^2 \right) * \frac{\ln(r / R_w)}{\ln(R_I / R_w)} \right\}$$

(Johnson et al., 1988).

While not explicitly represented, the soil properties do influence the steady-state pressure distribution because the radius of influence (R_I) does vary as a function of permeability.

<u>MSW Conductivity</u>

The hydraulic conductivity of MSW basically governs the movement of leachate and gases within a landfill. Numerous laboratory and field tests have been conducted to determine

the permeability of MSW. Unfortunately, the range of values found in the literature spans four orders of magnitude.

To convert the hydraulic conductivity values to the conductivity of landfill gas, the intrinsic permeability, k, can be solved using the following relationship

$$k = K_h \mu_w / \rho_w g \, ,$$

then to convert k to the conductivity of landfill gas, K_g, the viscosity of the landfill gas, μ_g, at the given temperature must be known. In the temperature range of 80° to 189°F, the viscosity of landfill gas can be approximated by

$$\mu_g = (0.0125 \text{ to } 0.0150) * \mu_w \text{ at } 69°F.$$

(Tchobanoglous et al., 1993).

Substituting,

$$K_g = k \rho_w g / \mu_g \, .$$

Table 2.5 is a summary of some of the values found in the literature. Note: These values have been adjusted to reflect the conductivity of landfill gas at 40°C.

Table 2.5:

Source	Gas conductivity (ft/yr)
Ham, et al.	6.9E3 to 6.9E4
Tchobanoglous, et al.	7.5E4 to 7.5E6
Young, et al.	2.1E3
Shank	2.2E4

Landfill Gas Flow

Because of local gas generation, flow to a well using Darcy's Law and the continuity equation will be different than those developed for soil venting systems. By making the following assumptions about gas flow, gas generation, k, ρ, and the boundary conditions to the continuity equation, an equation for flow to a well was developed.

Assumptions:

- The system is at steady state.
- There is horizontal, uniform radial flow to the extraction well.
- The generation rate of gas is spatially constant and uniformly distributed.
- Density and temperature are constant.
- The radius of influence, R_I, is constant and produces a cylinder that has a constant height, z.
- The MSW is homogeneous and isotropic.
- Flow across the boundary where $r=R_I$ is zero.

- The flow at the well is equal to the total volume of waste within R_I multiplied by its gas generation rate.
- Flow is laminar.
- The radial pressure distribution = P(r). Where $r=r_W$, $P(r)= P_W$.
- Waste leachate saturation is constant.

Equation Development. Given these assumptions, the following can be developed developed: (Schumacher, 1983)

$$Q_t = \pi R^2{}_I zq \ ,$$

where Q_t is the total flow at the well from the well area, q= (volume of gas produced)/(volume of waste-year). Using Darcy's Law it is found that

$$Q_r = K_g(2\pi r)z\frac{dp}{dr}$$

where Q_r is the variable radial flow. Employing the continuity equation and the assumptions outlined above, the following may be derived:

$$Q_r = \left(\pi R_I{}^2 - \pi r^2\right)zq \ .$$

By setting these equal to each other and integrating, an equation for the pressure as a function of the radial distance in a control volume where gas is being generated is developed

$$\left(\pi R_I{}^2 - \pi r^2\right)zq = K_g(2\pi r)z\frac{dp}{dr}$$

$$\frac{q}{2K_g}\left[\frac{R_I^{\,2}}{r}-r\right]dr = dp$$

$$\frac{qR_I^{\,2}}{2K_g}\int_{r_w}^{r}\frac{dr}{r}-\frac{q}{2K_g}\int_{r_w}^{r}dr=\int_{P_w}^{P_r}dp$$

$$\frac{q}{2K_g}\left(R_I^{\,2}\left[\ln|r|-\ln|r_w|\right]-\frac{1}{2}\left(r^2-r_w^2\right)\right)=p_r-p_w$$

(Schumacher, 1983).

Active Collection Systems

Gas Collection

Collection systems are one way in which landfill gas may be managed. These systems use a series of wells or trenches in the MSW, which serve to collect the gas and allow it to be withdrawn from the MSW. Individual wells are connected to a common header that is, in turn, connected to a series of centrifugal blowers. From there, the gas is transported to an energy conversion system or flare.

When a vacuum is applied at the well head, a radius of influence is created that extends into the MSW. The radius of influence is dependent on the vacuum applied, the gas generation within the waste and the permeability of the waste. Radius of influence, R_I is defined as the distance from a well at which there is no apparent vacuum from the gas extraction system (Schumacher, 1983). It is recommended

that, initially, one or more test wells be sunk into the waste to determine the gas generation rates, and the optimal negative pressure that can be applied without introducing a flow of air into the waste (Ham et al, 1979). Based on these data, the radius of influence can be determined for the well. With the radius of influence, a well field then can be designed to collect the gas being generated while maintaining an anaerobic environment.

Withdrawal of the gas at rates higher than the biological production will lead to a reduction of pressure below atmospheric pressure with the potential introduction of air into the landfill. This not only destroys the anaerobic environment needed for methanogenesis, but also tends to introduce excessive quantities of nitrogen and oxygen into the product gas. If the product gas is used for energy conversion, the latter will lower the energy value of the gas. The wells should be spaced such that a radius of influence of around 100 to 200 feet is established for landfills with a cover system that incorporates an impermeable geomembrane (Tchobanoglous et al., 1993). Additionally, it is recommended that a vacuum at the wellhead of 10 inches of water column be applied (Tchobanoglous et al., 1993).

<u>Gas Condensate</u>

Condensate forms when the warm gas being extracted is cooled by the surrounding air as it transported through the

header to the blowers. Gas collection headers are usually installed with a 3 percent slope to a condensate sump to handle to moisture which drops out of the gas. Based on a flow of 1000 scfm and a temperature range of 90 to 130 °F, Tchobanoglous estimated (using the Ideal Gas Law) that the moisture would fall out at a rate of 900 gal/day. Appendix A contains an example of his calculations.

CHAPTER 3
SITE DESCRIPTION

Site Location

The site selected for this study was the Alachua County Southwest Landfill (ACSWLF), located in Alachua County, Fl, approximately two miles southwest of the town of Archer, Fl (see Figure 3-1). This 145-acre site was an active landfill in Alachua County during the period of this study. Though predominantly surrounded by land used for agricultural purposes, many of the residents of Archer often complained about the smell created by the landfill gas and about the potential threat to the groundwater from the MSW leachate.

With an approximate elevation between 70 and 125 feet above sea level, the land surface in the vicinity of the landfill is mainly made up of rolling sand hills and depressions. Directly beneath the site (55 to 65 feet) is the Floridan Aquifer, which serves as the primary drinking source for the residents of Alachua and surrounding Counties. The hydraulic conductivity of the Floridan Aquifer in this region has been estimated at approximately 3.9×10^{-2} cm/sec (110 ft/day), based on an aquifer thickness of 200 feet and an aquifer porosity of 20 percent (Sproul, 1986, as cited in CH2M-Hill and ESE, 1986). Actual groundwater flow has been estimated to be between 3.5×10^{-4}

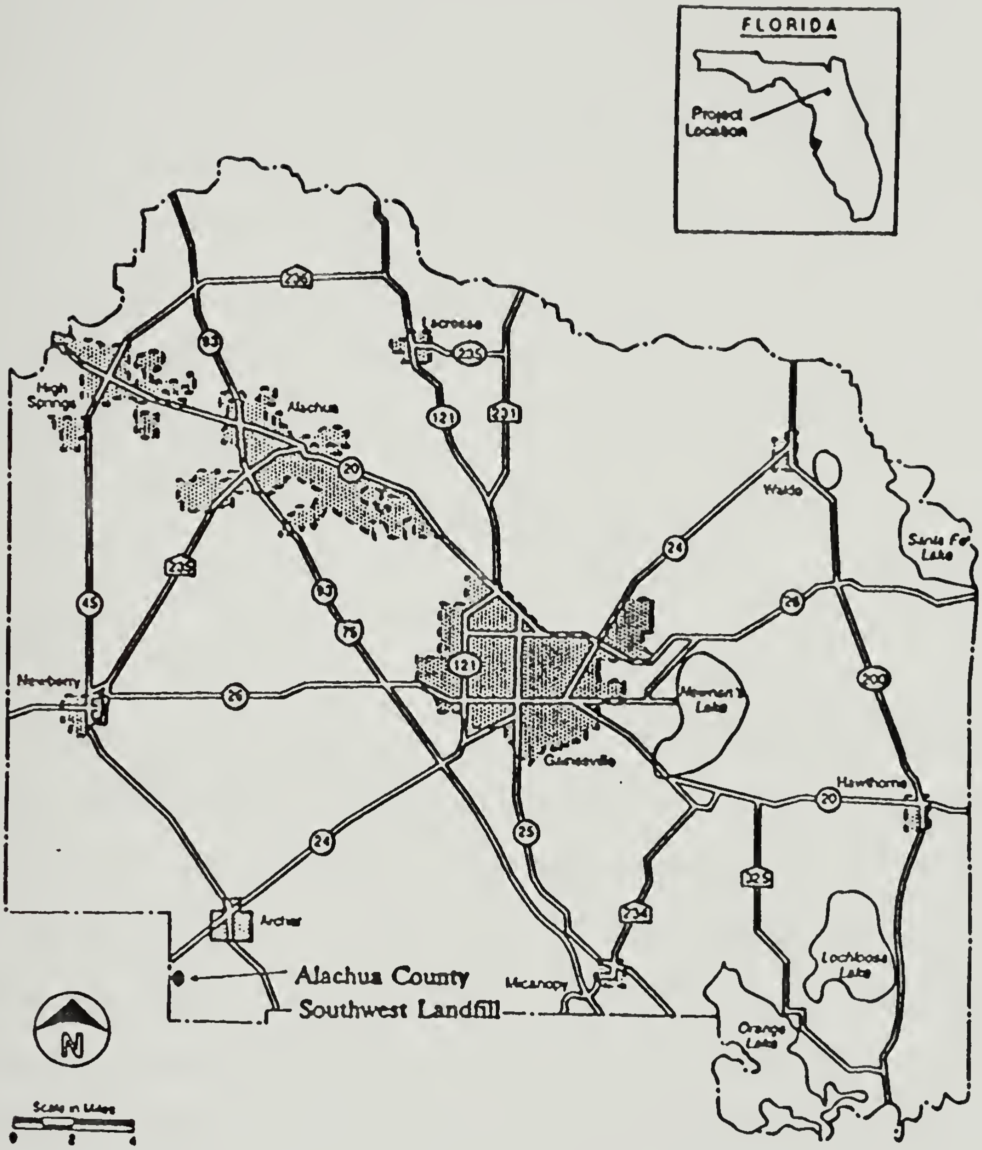

Figure 3-1: Alachua County Southwest Landfill Location (CH2M-Hill, 1992)

and 1.1 x 10^{-3} cm/sec (1 to 3 ft/day) moving in a northeasterly direction as shown in Figures 3-2 and 3-3 (CH2M-Hill and ESE 1986).

As outlined in Figure 3-4, the landfill consists of three distinct Class 1 sections or units. Unit I is a 30-acre area in which MSW was placed during the period 1973 to 1985; Unit II is an 11-acre area in which MSW was placed from 1985 to 1988; and Unit III, a 27-acre area, has received waste since 1988 and continues as an active fill.

Site Characteristics

Unit I

The 30-acre unlined unit was operated initially during the period prior to the Resource Conservation and Recovery Act (RCRA) and therefore little attention was paid to the material placed in this area. The operation of the unit used the open-end area method of landfilling, in which an area was excavated and then backfilled with MSW. As the excavated area was filled, the area along the active face was excavated to provide more room for additional MSW and also to provide cover material for the MSW. The waste was placed in two-foot lifts and then compacted. Based on the estimated 50-foot depth of fill and a placement density of 415 pounds per cubic yard, there are approximately 1.86

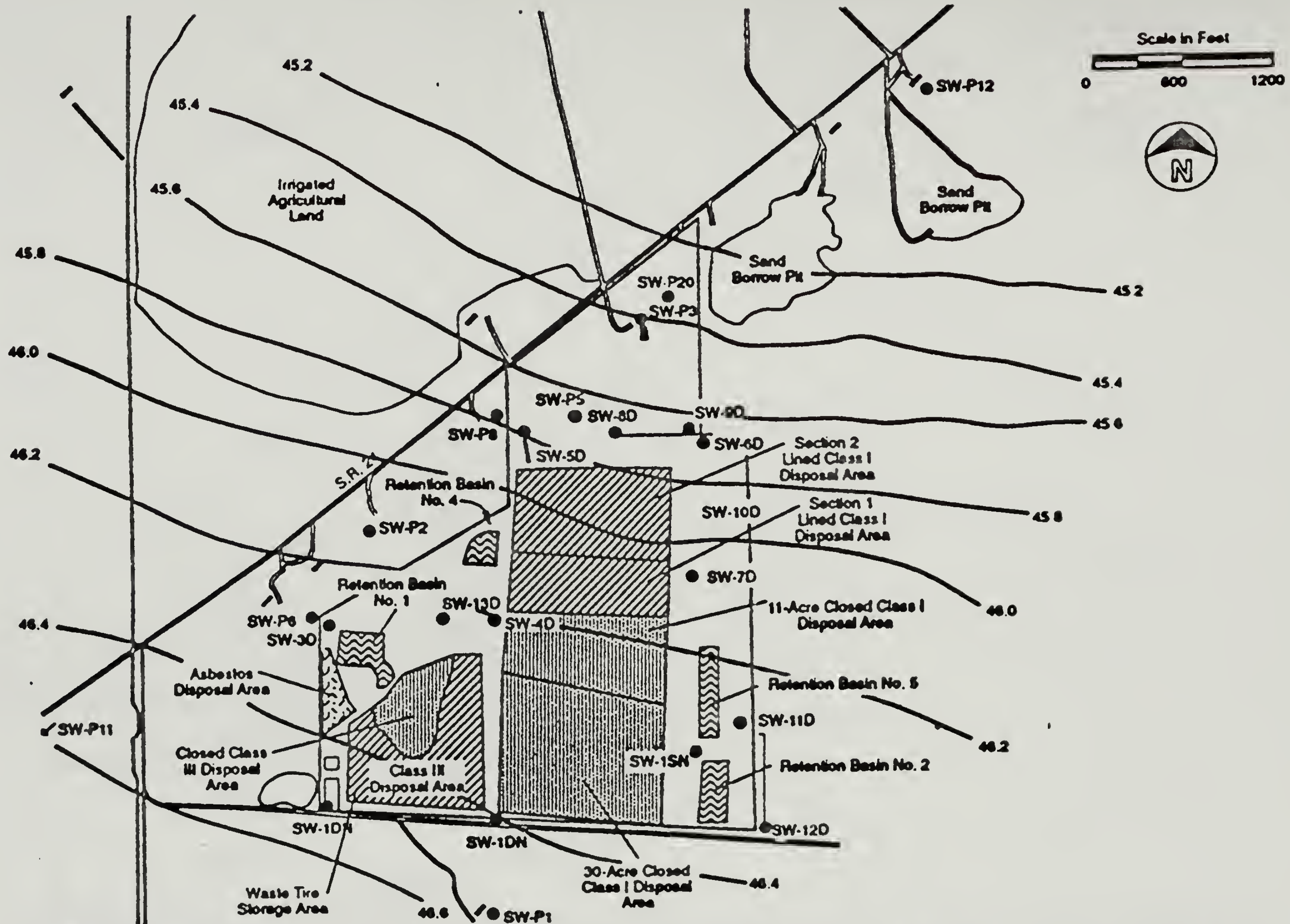

Figure 3-2: Potentiometric Surface at ACSWLF, Floridan Aquifer, January 1991 (CH2M-Hill).

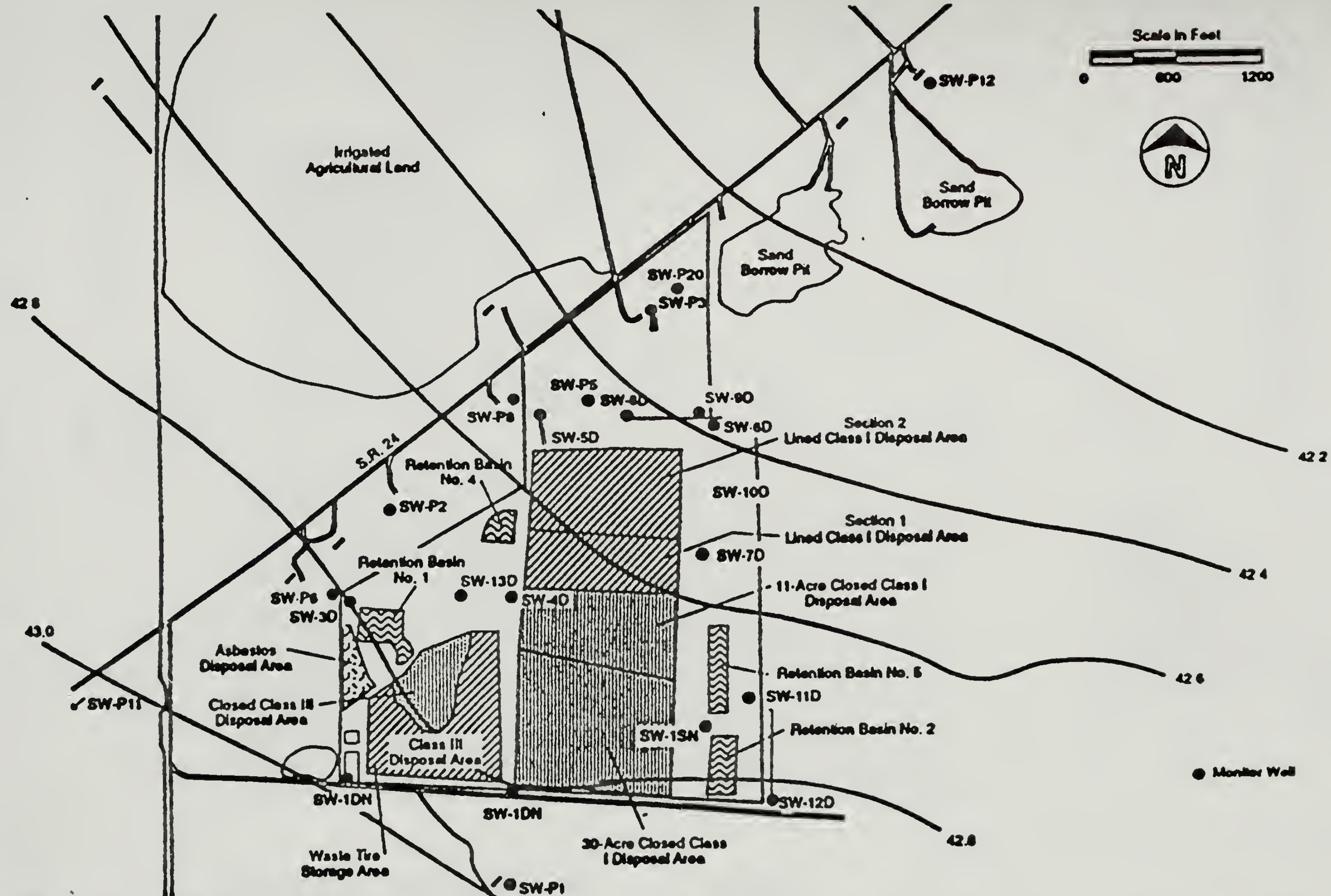

Figure 3-3: Potentiometric Surface at ACSWLF, Floridan Aquifer, July 1991 (CH2M-Hill).

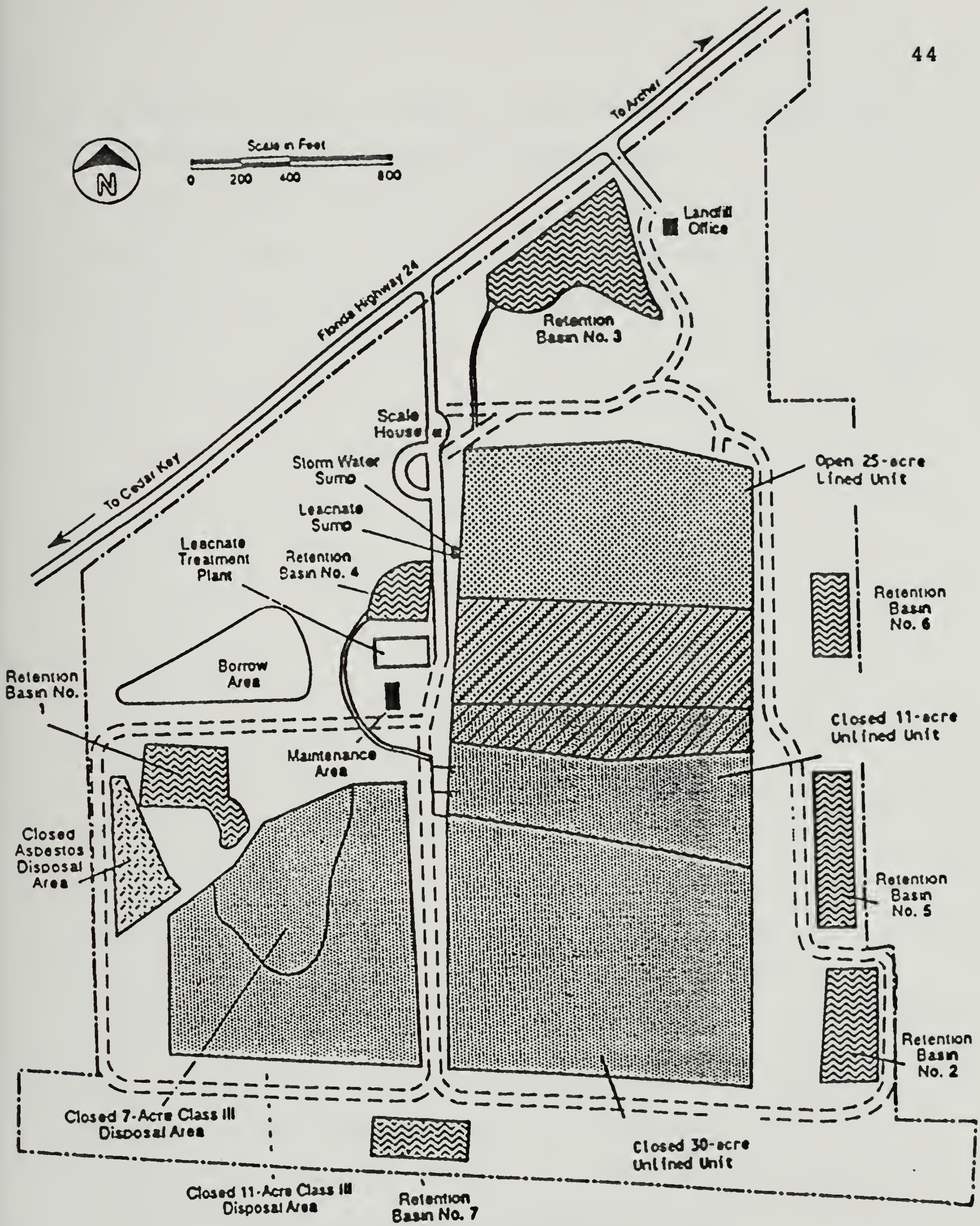

Figure 3-4: Alachua County Southwest Landfill (CH2M-Hill).

million cubic yards, or half a million tons, of MSW in Unit I (CH2M-Hill, 1986 as cited by Shank, 1993).

The primary waste placed in this section consisted of municipal refuse. However, on three documented occasions, hazardous waste was known to have been placed. The first instance, in 1978, involved a 55-gallon barrel of 70 percent hydrofluoric acid from a dumpster at a Mini-Mart. The top six inches of the barrel were completely corroded and the liner was cracked. Bicarbonate was placed on the barrel and the barrel was relocated to the southwest corner of Unit I. Water was continuously sprayed on the barrel and an additional two loads of bicarbonate were dumped to dilute the acid (Ferland, 1978 as cited in CH2M-Hill and ESE, 1986). The second occasion occurred in 1979. Several unsealed barrels were discovered in retention basin #1 (see Figure 3-4). The exact contents of the barrels were unknown, but the soil sample test results indicated the presence of 5-fluorocil and uracil. The barrels were removed and placed in a hazardous waste landfill, but the contaminated soil was placed in Unit I (Darabi, 1983 as cited in CH2M-Hill and ESE, 1986). The third occasion occurred in 1985 when Bear Archery deposited a leaking barrel of unsolidified epoxy resin. The Florida Department of Environmental Regulation's (FDER) position at that time was that hardened epoxy was not hazardous, but the unsolidified resin needed to be handled as hazardous waste.

Therefore, the barrel was removed (Burke, 1985 as cited in CH2M-Hill and ESE, 1986). Besides these three instances, the site was known to have accepted grease trap waste and septic tank sludge (Nelson, 1986 as cited in CH2M-Hill and ESE, 1986). It is also likely that waste from local hospitals was placed into Unit I, but there was no documentation of the quantity or quality of this waste. Table 3.1 is a breakdown by year of the quantites of waste placed into Units I, II, and III.

In 1985, samples from groundwater quality measurements confirmed contamination from two plumes extending to the north and east of the site. The plumes were suspected to be from Unit I. They contained chlorinated organics, high levels of total dissolved solids, ammonia and other aromatic compounds (CH2M-Hill, 1986). As a result of these contaminant plumes, FDER issued a Consent Order to Alachua County to cover the 30 acre sight with an impermeable cap to prevent any further migration of rain water into the MSW stored in Unit I. This was completed in 1987. In conjunction with the capping of Unit I, gas vents were installed. Their initial purpose was to vent landfill-generated gases that could have pressurized the unit and eventually cracked the newly installed cap.

The horizontal hydraulic conductivity of MSW in Unit I was characterized by Shank (1993) as approximately 3.2×10^{-4} cm/sec. Additionally, Shank developed a profile of the

Table 3.1: Annual Refuse Disposal per Year for ACSWLF (CH2M-Hill, 1992).

	Tons of MSW		
Year	30-acre	11-acre	27-acre
1972	60256		
1973	73944		
1974	79632		
1975	85320		
1976	91008		
1977	96696		
1978	102384		
1979	108072		
1980	113760		
1981	119448		
1982	125136		
1983	130824		
1984	136512		
1985		156370	
1986		126815	
1987		126815	
1988			96173
1989			119987
1990			124322
1991			119600
1992			120000

standing leachate levels in Unit I. Figures 3-5 to 3-11 indicate that in some areas of Unit I, approximately 20 feet of leachate is ponded in the MSW. Because of the amount of leachate and the conductivity of MSW, even though the unit has been capped, there exists the potential for leachate and its contaminants to move off site and contaminate the Floridan Aquifer.

In 1992, Manley (1992) examined the gas production rates in all three units. Figures 3-12 to 3-14 indicate the approximate flow rates and pressures in the wells installed in the MSW. Data for Unit III was suspect as the unit had not yet been capped. By disregarding the Unit III data, Manley concluded that the 11-acre unit still was actively producing gas, while a major portion of the 30-acre section had basically ceased production. A study of the gas concentrations produced by the MSW at the wells was conducted by Dwyer. Table 3.2 is a summary of her results (Dwyer, 1992).

Unit II

The 11-acre unlined area was operated as an interim disposal area between the 30-acre area and the newly constructed 27-acre area. The method of disposal was similar to that used in the 30-acre area. In 1987, Alachua County was authorized by FDER to raise the final grade for this area by nine feet over the closed area, as construction

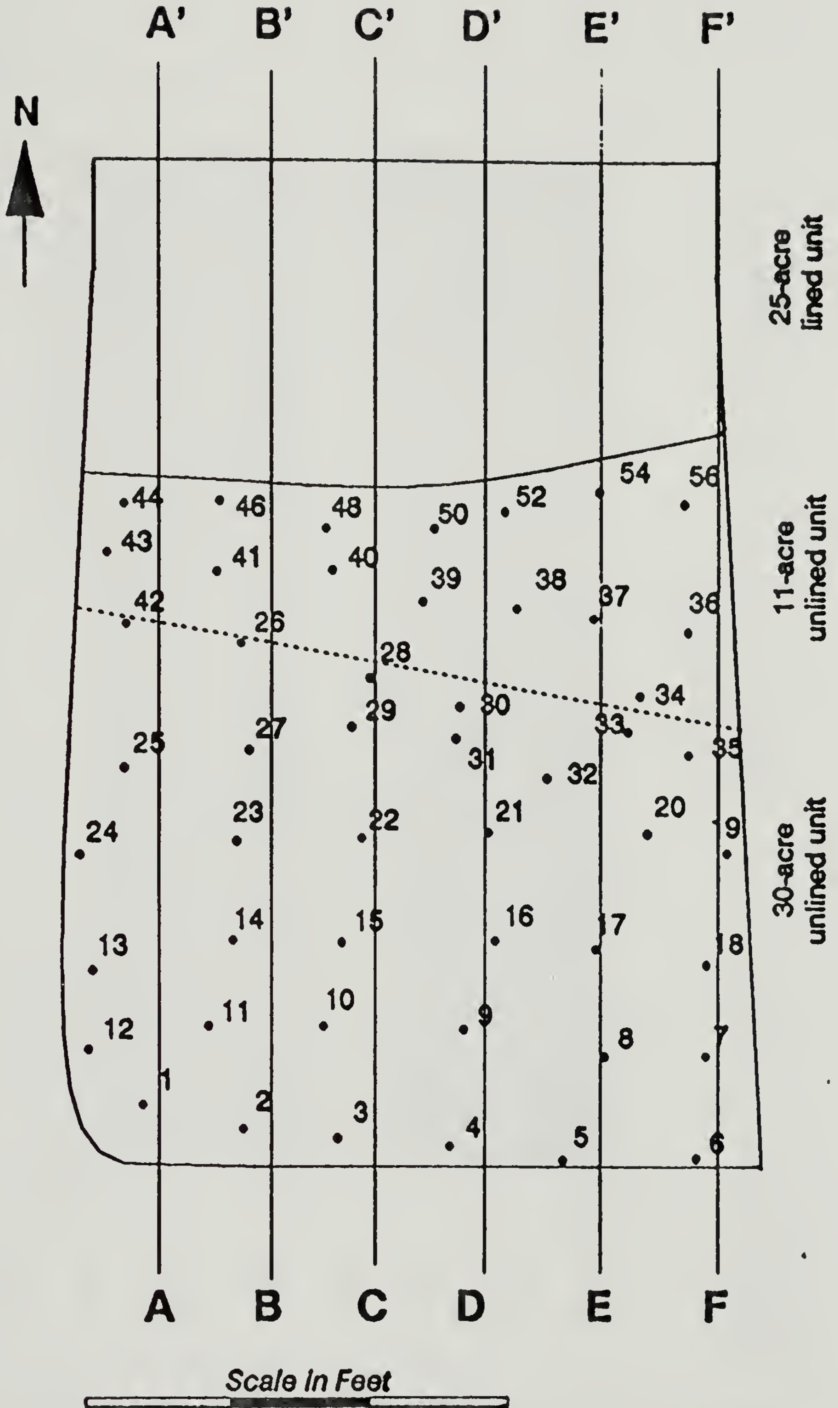

Figure 3-5: Gas Well Layout with Cross-sections Shown (Shank, 1993).

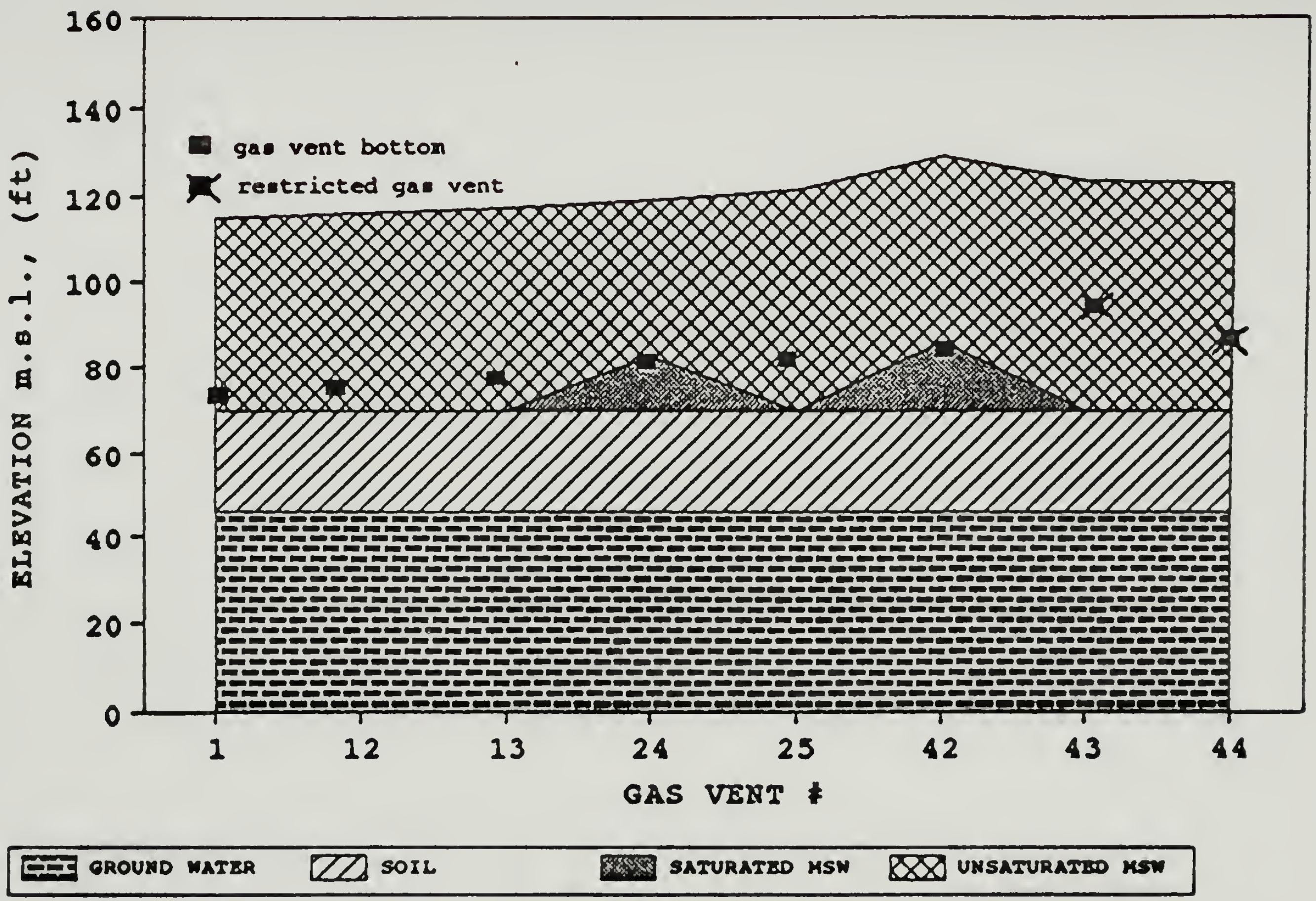

Figure 3-6: 30-acre and 11-acre Unit Cross-section A-A' (source Shank, 1993).

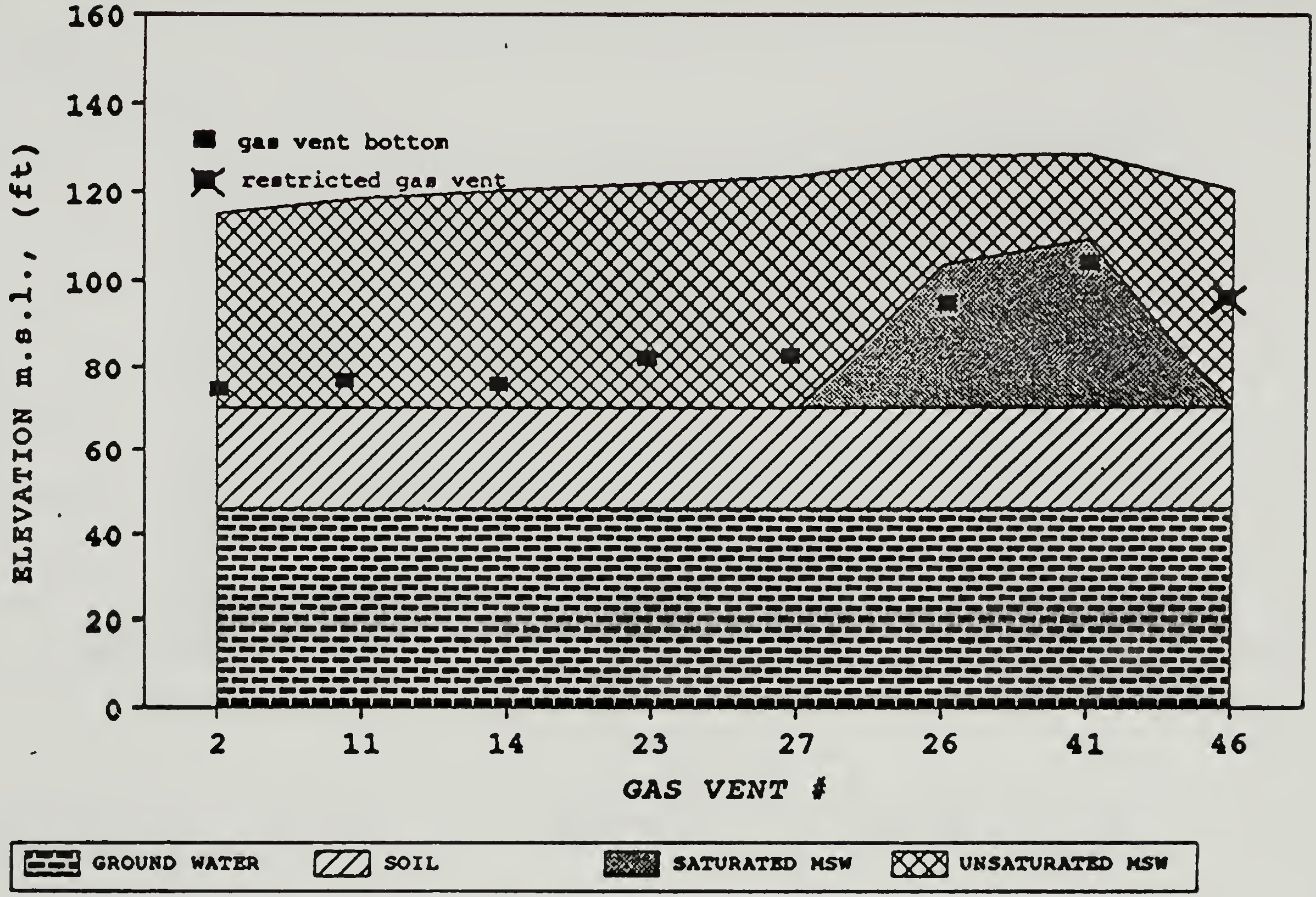

Figure 3-7: 30-acre and 11-acre Unit Cross-section B-B' (source Shank, 1993).

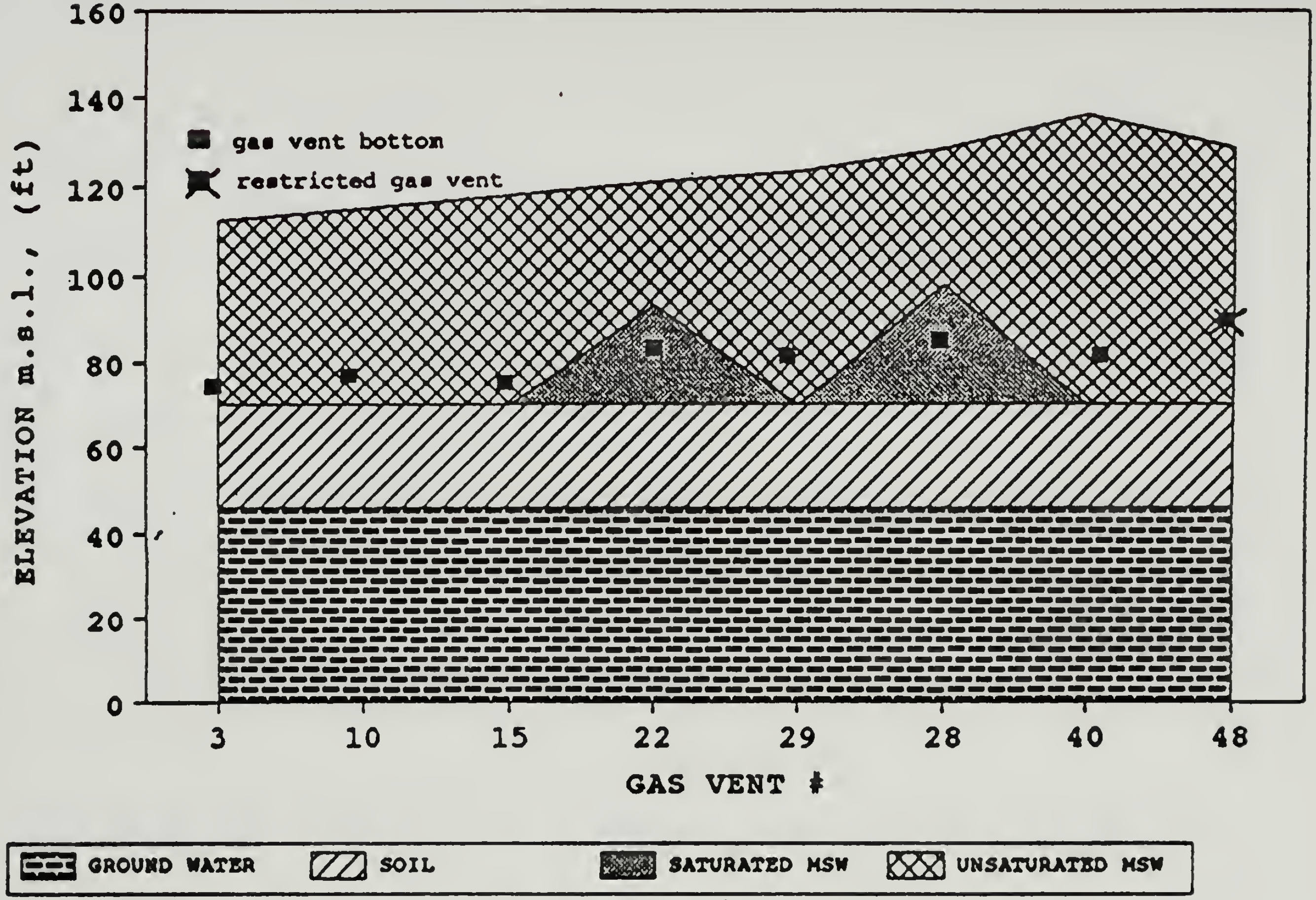

Figure 3-8: 30-acre and 11-acre Unit Cross-section C-C' (source Shank, 1993).

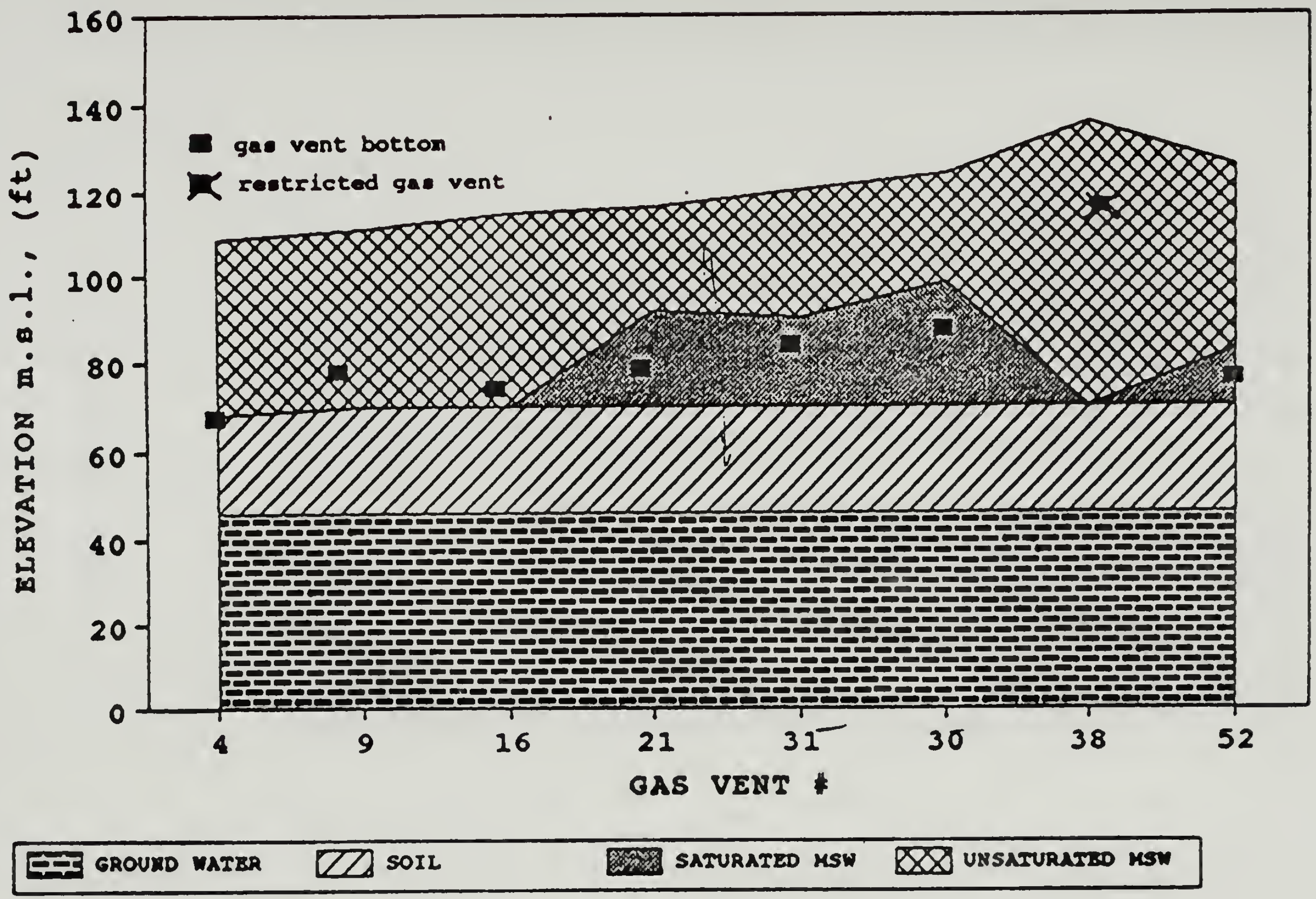

Figure 3-9: 30-acre and 11-acre Unit Cross-section D-D' (source Shank, 1993).

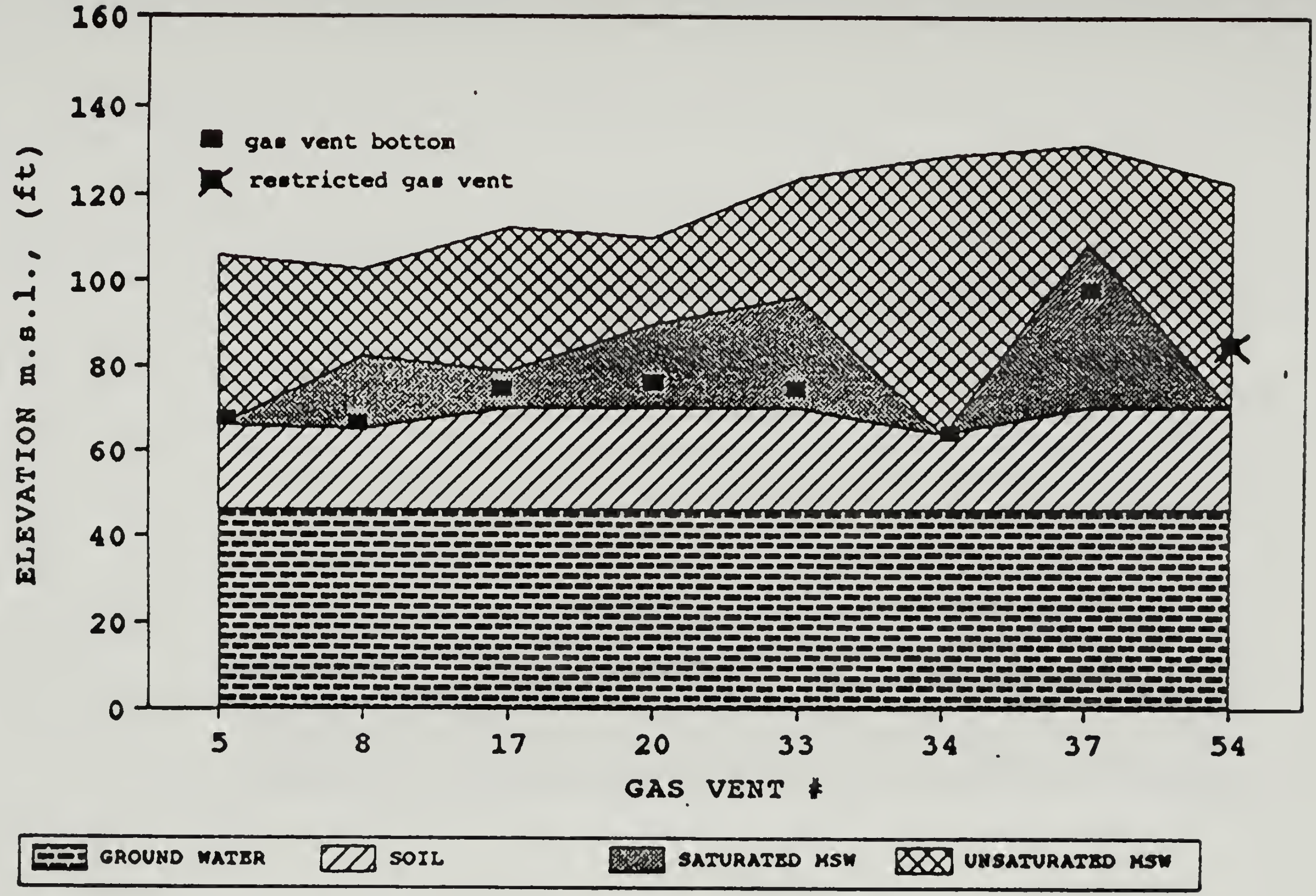

Figure 3-10: 30-acre and 11-acre Unit Cross-section E-E' (source Shank, 1993).

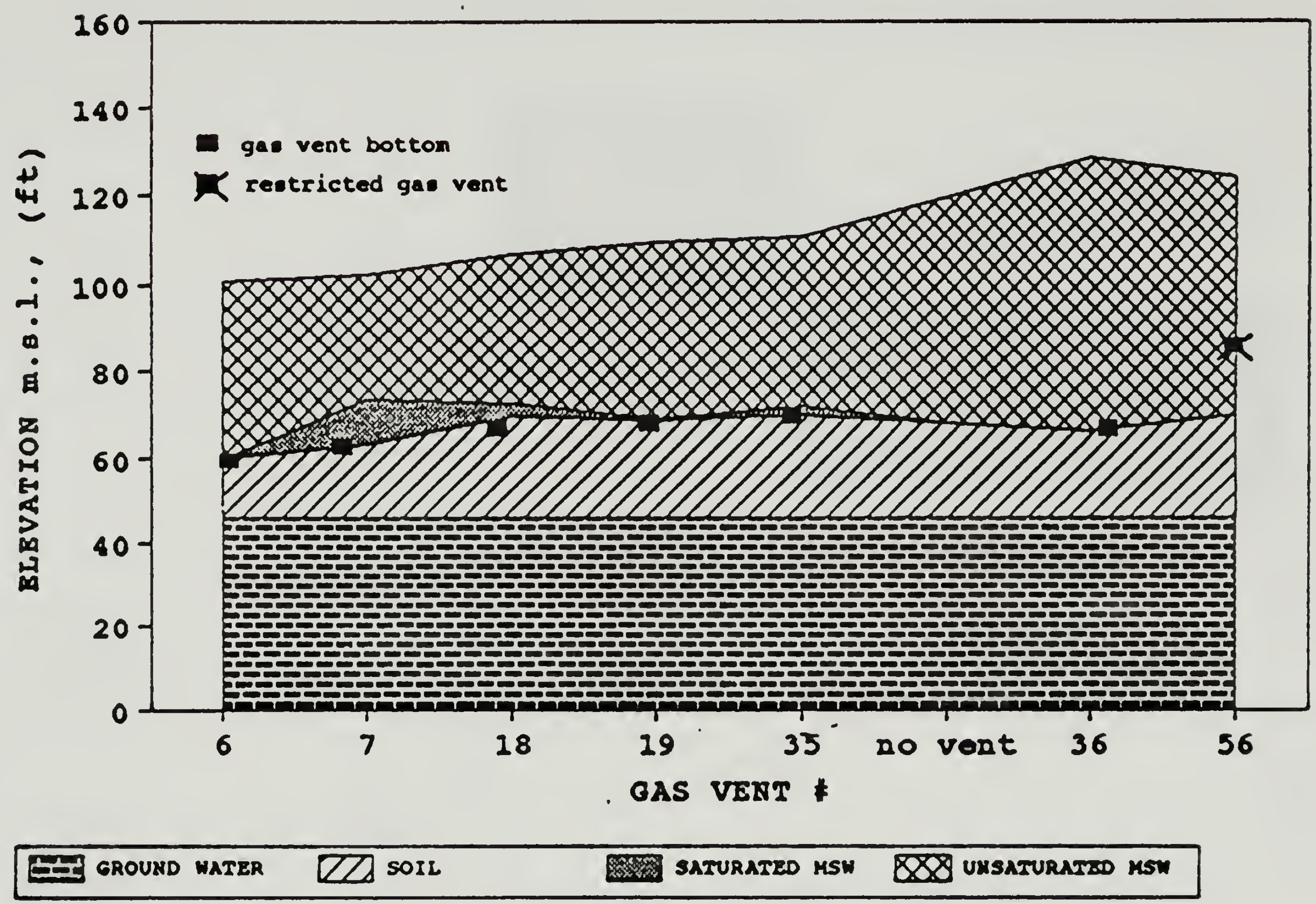

Figure 3-11: 30-acre and 11-acre Unit Cross-section F-F' (source Shank, 1993).

Vent ID#	Avg Flow (scfm)		Sum of Avg flow (scfm)	Sum of Avg flow (scfd)
43	0.59		8.84	12726.60
44	0.52			
46	0.51			
41	BDL			
40	0.82			
48	0.55			
50	0.51			
39	0.89			
38	1.08			
52	0.64			
54	0.65			
37	0.97			
34	0.38			
36	0.39			
56	0.35			
42		0.22	2.04	2941.35
26		0.30		
27		0.20		
29		0.26		
28		0.28		
30		0.22		
31		0.20		
32		0.19		
33		0.19		
All Vents			13.12	18886.67

Figure 3-12: Values for Average Flows in ACSWLF gas wells (Manley, 1992).

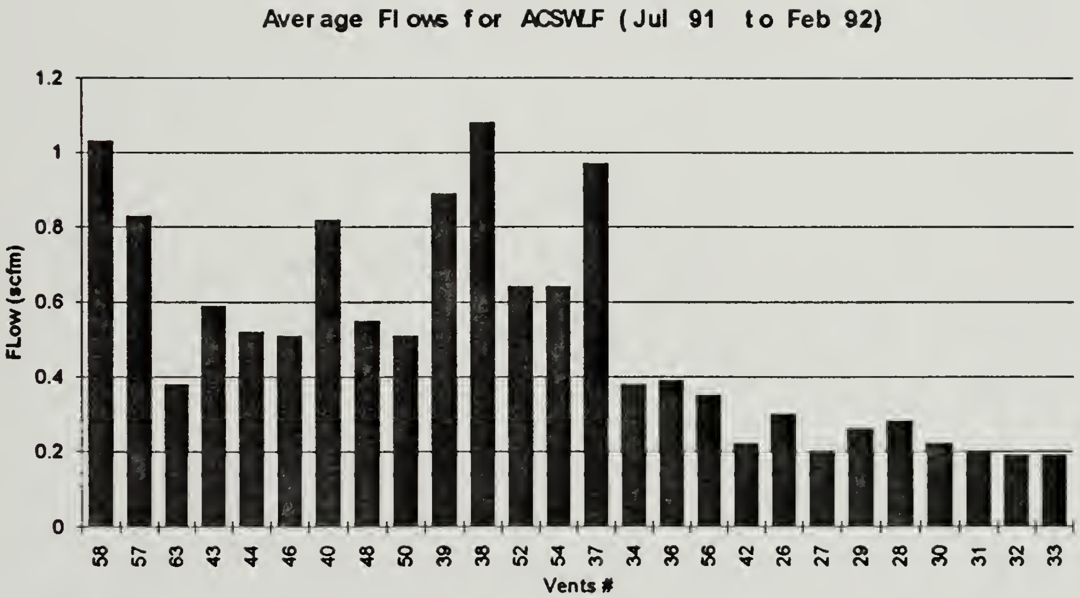

Figure 3-13: Gas Well Average Flows, Passive Venting (Manley, 1992).

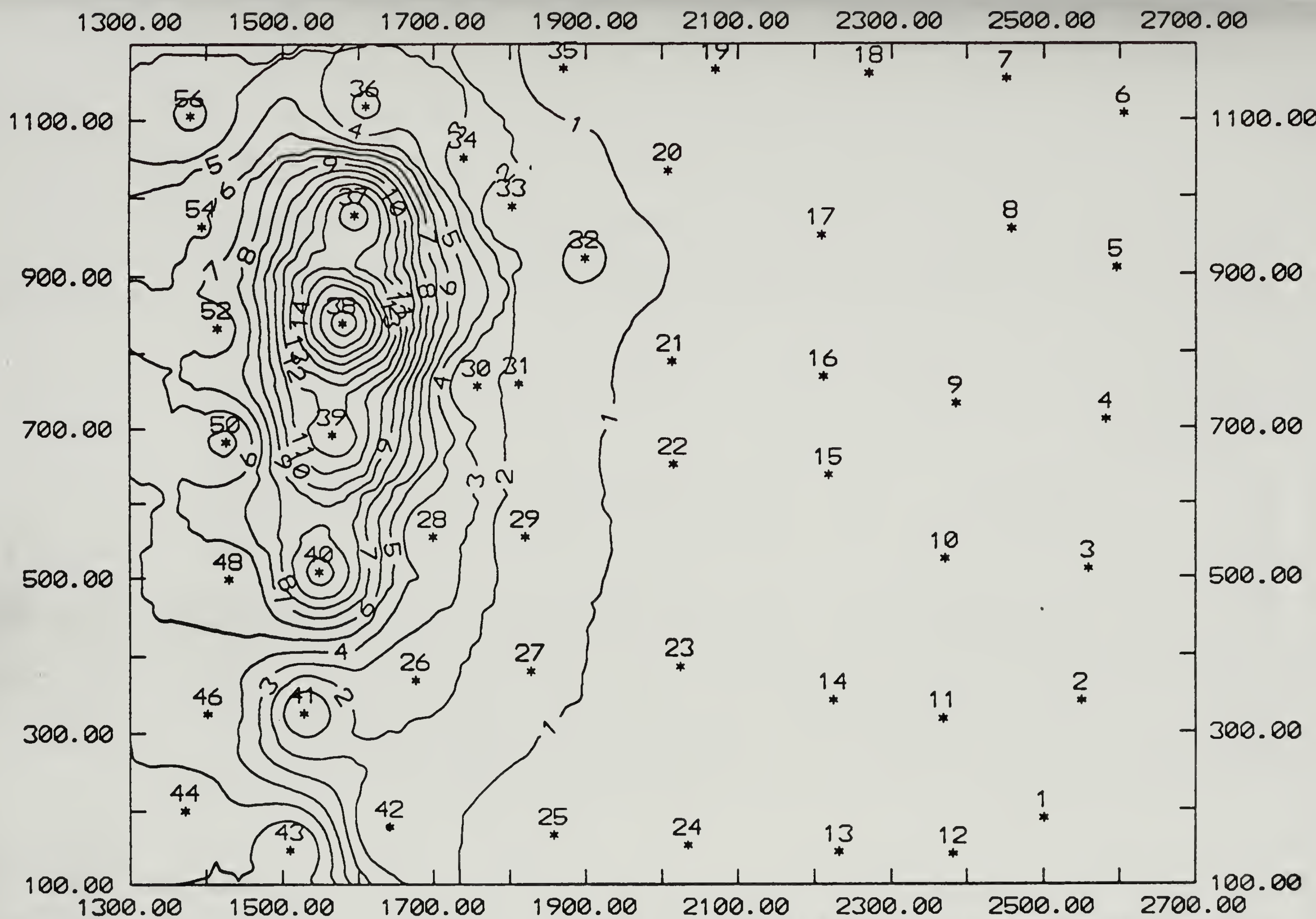

Figure 3-14: Gas Well Pressure Contour Map Measured at No Flow, " H20 (Manley, 1992).

Table 3.2: Gas Composition at Gas Wells During Passive Venting.

Well #	%CH4	%CO2	%O2	%N2
1	no flow			
2	no flow			
3	no flow			
4	no flow			
5	no flow			
6	54.7	44.2	0	0
26	55.6	44.7	0	0
8	61.4	40.3	0	0
9	61.2	40.1	0.5	0
10	62.8	37	0	0
11	61.5	37.5	0.4	0
12	no flow			
13	59.1	40	0.7	0
14	61.7	36.6	0.6	0
15	63.2	36.6	0	0
16	no flow			
17	63.4	34.7	0.6	
18	59	43.7	0.3	0
19	61	40.5	0	0
20	61	38.9	0.2	0
21	61.2	38.7	2.1	0
22	63.6	39.4	0.3	1.2
23	61.2	40.9	0.5	0
24	61.2	38.9	1.3	0
25	58	38.4	1.8	0
26	59.4	41.2	1.8	0
27	65.8	38.9	0	0
28	61.7	42.2	0	0.7
29	62.8	41.1	0.2	1
30	61.2	40.3	0	0
31	58	42	0	0
32	64.7	38.9	0	1.3
33	57.7	37.4	0.4	2.1
34	58.4	38.4	0.9	0
35	53.5	33.9	9.7	0
42	54.7	44.2	0	0

Table 3.2 (cont):

Well #	%CH4	%CO2	%O2	%N2
43	56	44.3	0	0
44	52.2	43.9	0	0
46	57.6	43.7	0.4	0
41	no flow			
40	55.7	44.9	0	0
48	56.5	44.8	0	0
50	57.3	44.2	0	0
39	55.4	44.8	0	0
38	55.7	44.9	0	0
52	54.5	45.2	0	0
54	57.3	44.4	0	0
37	55.3	44.8	0.4	0
34	49.2	43.3	0.3	0.4
36	55.8	44.6	0	0
56	55.2	43.2	0.4	0.4
57	55.9	39.9	0.3	1.6
58	56.2	41.7	0	0

of the 27-acre lined area had not yet been completed and the county needed additional storage space. Like Unit I, no detailed information exists concerning the composition of waste placed into this Unit. However, in 1985-86, a waste characterization study was conducted and the results are presented in Table 3.3. This indicates the quality of waste that was deposited in the 11-acre area.

In 1988, gas venting wells were installed in the 11-acre area. The final cover being placed in 1991. It was concluded that the refuse in Unit II still was actively producing gas (see Figures 3-12 to 14) (Manley, 1992).

In July 1992, Alachua County issued a contract to install a landfill gas flare system connecting the wells in Units I and II. Figure 3-15 provides an overview of this system. Presently, the gas simply is flared to the atmosphere for odor control.

Unit III

This area currently receives MSW and is designated as a Class I composite-lined landfill, with an installed leachate collection system. Construction of the landfill resulted in a fill volume of more than 2,161,000 cubic yards covering a 27-acre area (Townsend, 1992). Construction of the lined cell used the fill in Unit II as the berm for the south side. Gas wells were installed underneath the liner in this area to prevent ballooning by landfill gas generated in the

Table 3.3: MSW Characterization Data for the 11-acre Unlined Unit (CH2M-Hill, 1989).

Waste Category	Volume of waste in tons	
	1985	1986
Garbage	26,532	27,378
Brush	448	862
Liquid Waste	532	20
Tires *	40	40
Construction Debris *	6,053	8,763
Trash	1,279	1,362
Collection Centers	710	834
Road Dept.	445	192
Total	36,039	39,951

* Deposited in other designated landfill units and not in the 11-acre unit.

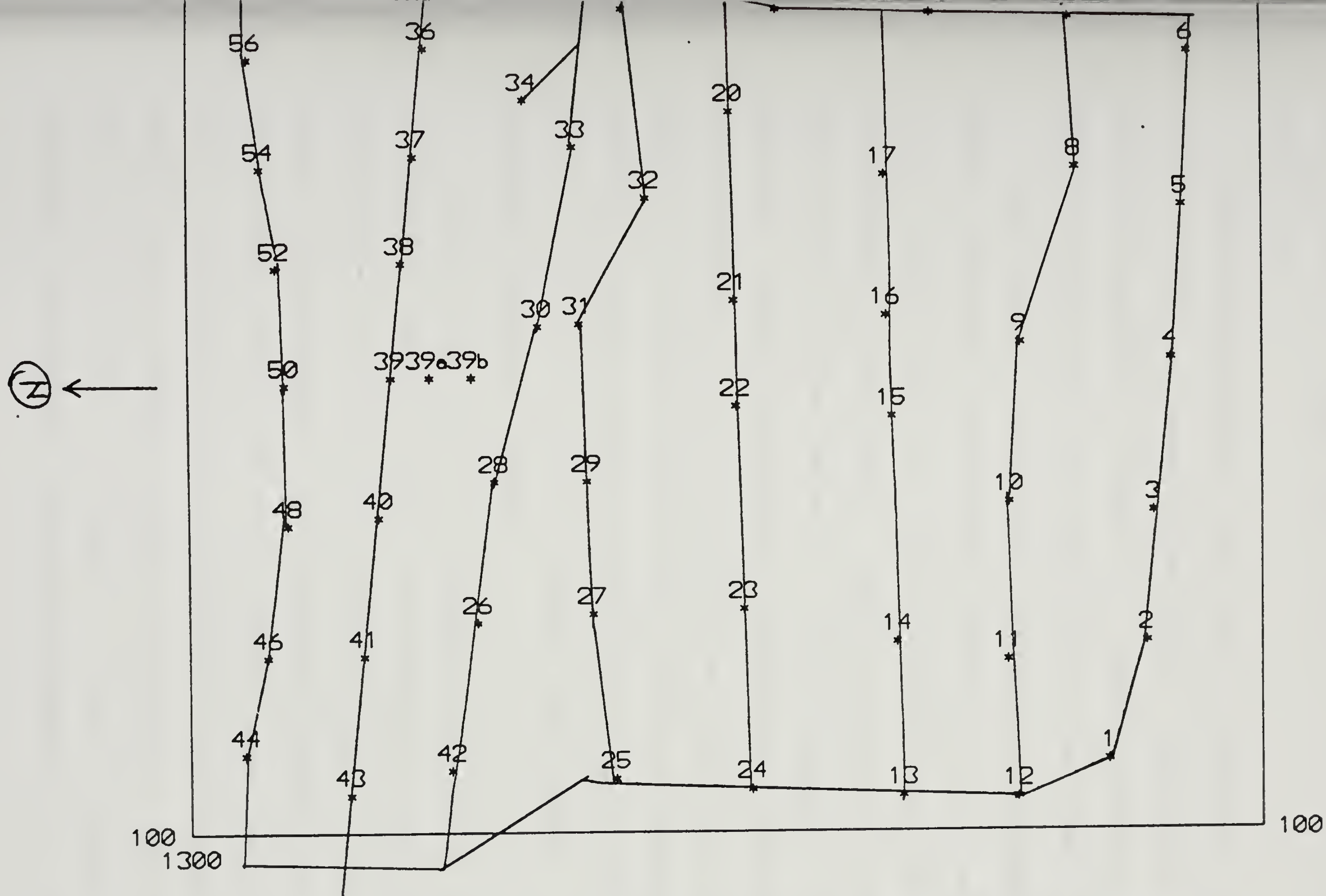

Figure 3-15: ACSWLF Gas Collection System Wellfield Layout (CH2M-Hill)

fill of Unit II. These wells are #45, 47, 49, 51 and 53 in Figure 3-15.

Solid waste placed in this area was studied in 1991 by TIA Solid Waste Management Consultants. The results of the study are presented in Table 3.4. Tires, construction debris and yard waste were not placed in the lined area.

The current research being conducted by Townsend and others in Unit III involves the recirculation of leachate through lateral injection lines to increase the rate of biodegradation of the waste. Figure 3-16 and 3-17 outline Unit III and the area where the lateral injection is being conducted. Results from Manley concluded that the gas flow rates observed were not representative of the actual gas production. This was because Unit III was not covered and, therefore, gas was escaping through the surface, the northern face of the cell and through the leachate collection clean-out laterals.

A study which used a flux chamber developed at the University of Central Florida was conducted to try and quantify the gas escaping through the uncapped surface. For the two areas examined, LFS1 and LFS2 of Figure 3-16, flux rates of 30.93 scm/hr and 16.59 scm/hr, respectively, were found. The difference was attributed to the fact that LFS1 was the area of leachate recylce and LFS2 was a control area. A total surface emission of 270 scfm of methane for the active cell was also reported (Reinhart et al., 1992).

Table 3.4: Composition for MSW at ACSWLF (TIA Solid Waste Management Consultants, 1991).

	Total Waste Landfilled			
Material	**Alachua County**	**Gilchrist County**	**Weighted Average**	**Class 1 Landfill Waste**
Newsprint	6.8	6.7	6.8	8.6
Corrugated Paper	11.1	9.4	11.1	14.1
High Grade Paper	2.9	1.7	2.9	3.7
Mixed Scrap Paper	8.2	3.4	8.1	10.3
Non-Recyc Paper	8.5	16.0	8.7	11.0
Plastic (PET)	0.3	0.4	0.3	0.4
Plastic (HDPE)	1.0	0.6	1.0	1.3
Other Plastic Cont	0.6	1.1	0.6	0.8
Film Plastic	4.4	5.0	4.4	5.6
Other Plastic	3.9	4.5	3.9	4.9
Glass - Other	0.0	0.0	0.0	0.0
Clear Glass Cont	2.2	4.2	2.2	2.8
Colored Glass Cont	1.1	1.4	1.1	1.4
Aluminum Cans	0.9	1.0	0.9	1.1
Tin/Steel Cans	1.5	3.1	1.5	1.9
Ferrous Metals	0.9	2.3	0.9	1.1
Non-Ferrous Metals	0.6	0.3	0.6	0.8
Rubber	0.6	0.9	0.6	0.8
Textiles	3.2	2.3	3.2	4.1
Leather	0.0	0.1	0.0	0.0
Food Waste	4.5	3.6	4.5	5.7
Yard Waste	4.4	2.9	4.4	-
Mixed Materials	2.7	2.9	2.7	3.4
C & D Debris	19.9	16.7	19.8	-
Ceramics	0.5	0.1	0.5	0.6
Miscellaneous	6.1	4.5	6.1	7.7
H. Haz Waste	1.0	1.0	1.0	1.3
Diapers	2.1	3.9	2.1	2.7

Note:Class 1 landfill waste calculated from total waste without yard waste and construction and demolition C & D) waste. Waste amounts expressed as percent of total.

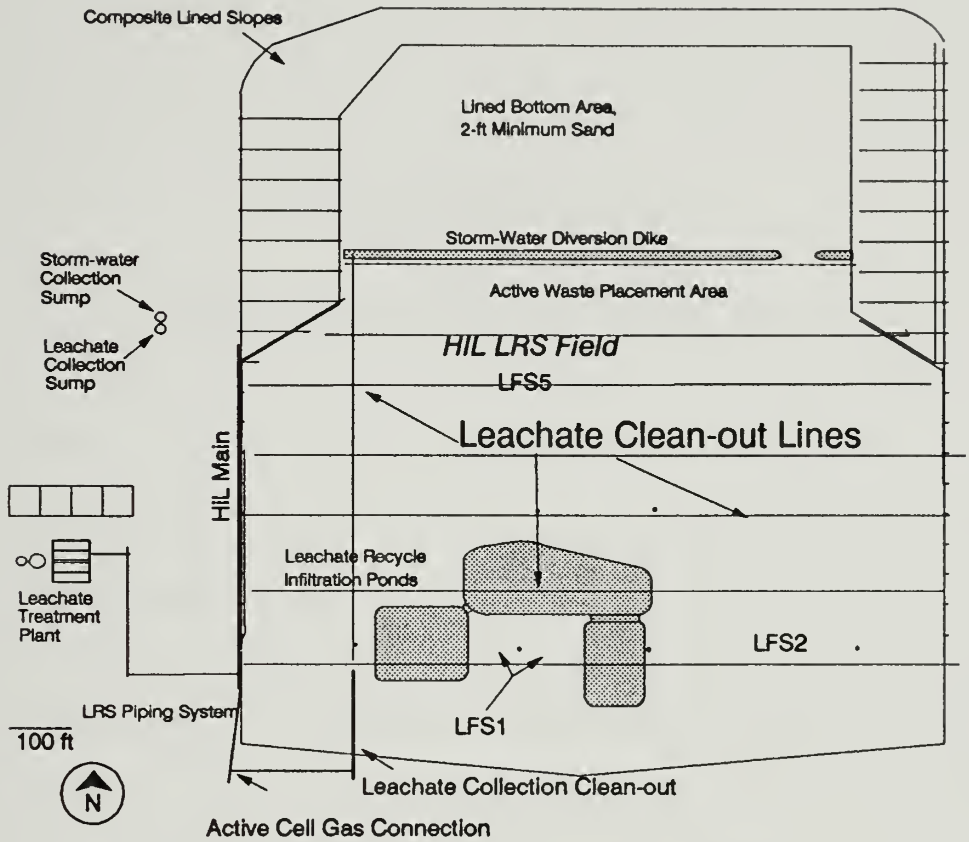

Figure 3-16: ACSWLF Lined Landfill Unit.

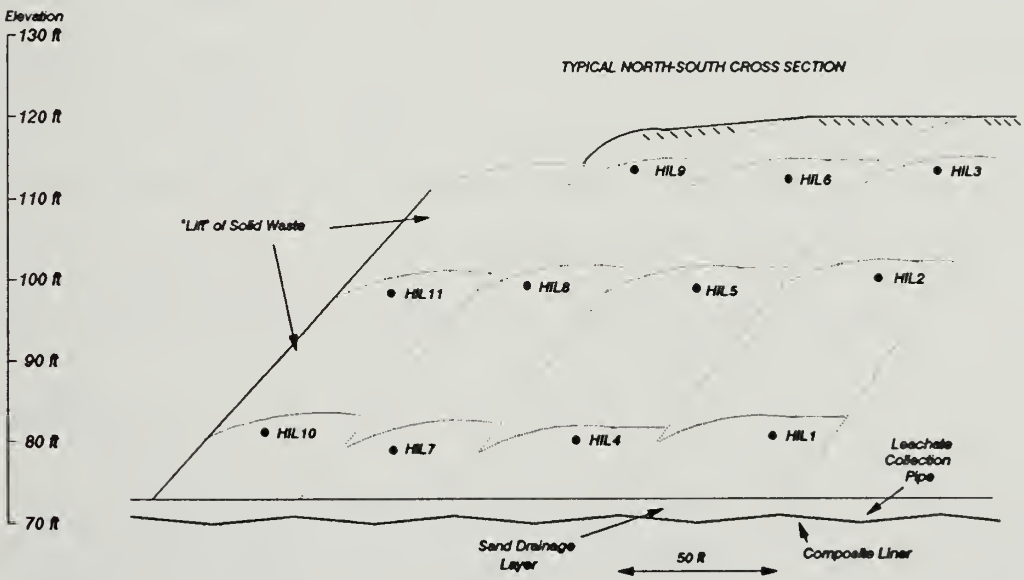

Figure 3-17: Horizontal Injection Lateral LRS (Typical Cross Section).

CHAPTER 4
METHODS AND MATERIALS

Sampling Equipment and Materials

Well Field

As shown in Figure 3-5, the well field at the Alachua County Southwest Landfill consists of 35 wells (#1-33, 35, and 43)in the 30-acre area and 20 wells (34, 36-54, 56) in the 11-acre area. Presently, there are 16 wells in the active area. The layout for the wells in the 27-acre active cell is such that the well spacing is in a set pattern of 250 feet apart in the north/south (N/S) direction, and 200 feet in the east/west (E/W) direction. Unlike the symmetrical pattern in the 27-acre area, the wells in the 30-acre and 11-acre areas were placed into the waste at varying intervals from one another. Some wells were spaced at 150-foot intervals from E/W and 200 feet N/S, while others were within 70 feet N/S, but 250 feet E/W.

Well Design

A typical well detail for all three areas is depicted in Figure 4-1. Well construction in the 30- and 11-acre areas began with drilling a two-foot diameter bore hole into

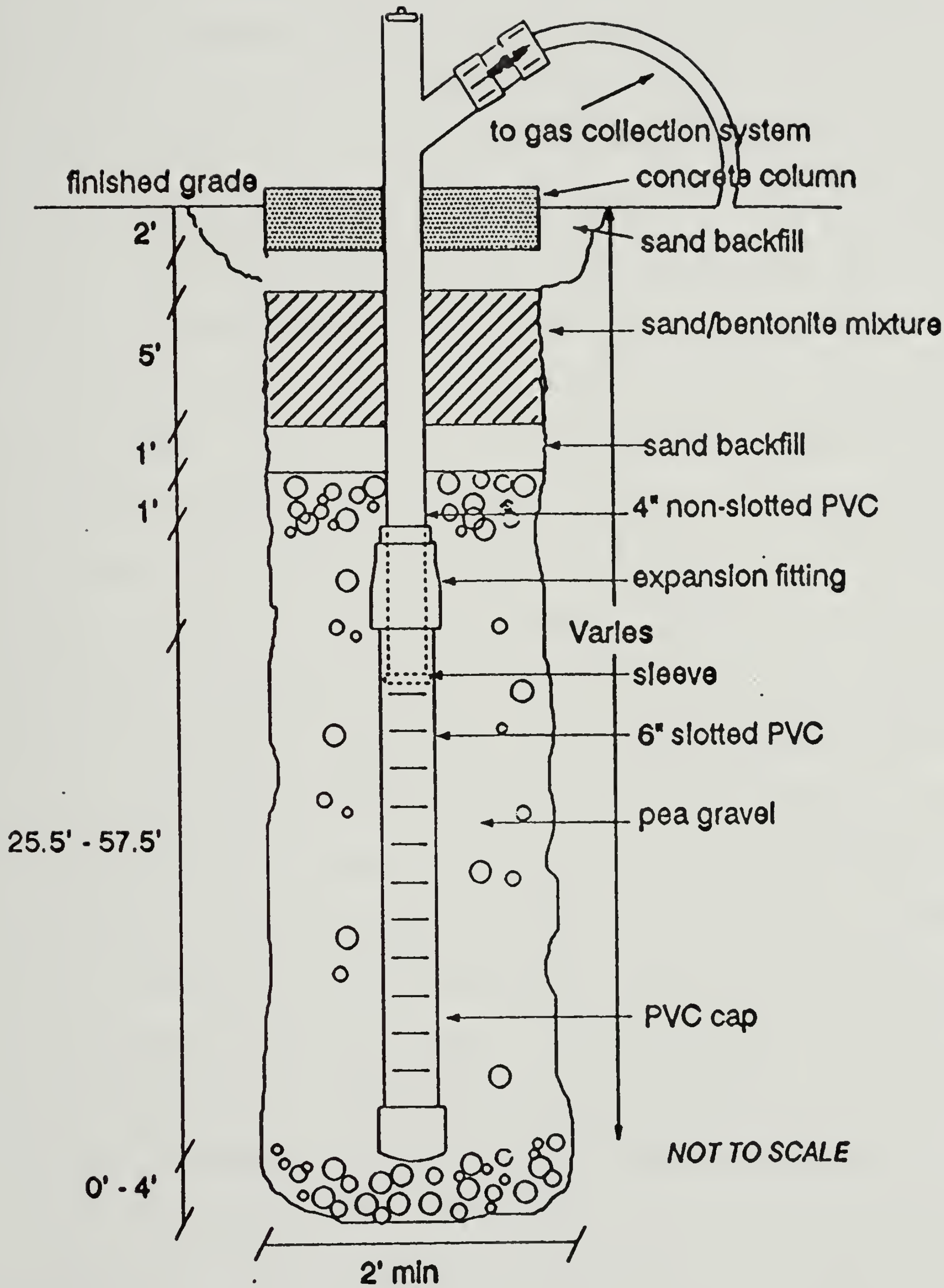

Figure 4-1: Typical 11-acre Unit Gas Well (Shank, 1993).

the MSW. The well depths for this site ranged from 28 to 35 feet. After the bore hole was completed, a six inch, schedule 40 screened PVC pipe was placed into the hole and backfilled with gravel. The makeup of the wells in the 30 acre site consist of a 20-foot, six-inch expansion section connected to a four inch PVC pipe section. This four inch section was screened over the bottom 15 feet. Table 4.1 is a summary of the construction details of these vents.

In the 11-acre area, the bore hole depths ranged from 26 to 71 feet. Additionally, the six inch screened portion of the well varied from 25.5 to 57.5 feet, with an average of 48 feet. The four inch connecting sections were not screened at all in the 11-acre area (CH2M-Hill). The bore holes were then sealed with a bentonite mixture. This was done to prevent air and water intrusion into the landfill. Over the last two to three feet of the bore hole, a concrete cap was placed to secure the wellhead. Table 4.2 shows the construction details of the 11-acre site's wells. Figure #4-2 is a detail of the wellheads in the 11- and 30-acre areas before this study began. Figure 4-3 is a detail of the 11-acre site's wellheads with an Accu-Flo retrofit wellhead installed. These will be discussed later.

In the active cell, the wells are placed as the refuse is deposited. To facilitate construction, a 20-foot steel casing surrounds the well, which is filled with gravel as the well height increases. As each lift is placed, the

Table 4.1: Construction Details of 30-acre Unit Wells (CH2M-Hill, 1992).

Gas Vent	Depth (ft)
1	35
2	34
3	34
4	35
5	35
6	35
7	34
8	35
9	28
10	35
11	34
12	34
13	35
14	34
15	35
16	35
17	35
18	35
19	35
20	35
21	35
22	31
23	35
24	35
25	35
26	35
27	34
28	35
29	35
30	35
31	35
32	35
33	35
35	29
42	35

Table #4.2: Construction Details of 11-acre Unit Wells (CH2M-Hill, 1992).

Gas Vent	Depth (ft)	Length of 4" section
34	63	47.5
36	50	33.5
37	63	50.5
38	60	41.5
39	70	57.5
40	70	57.5
41	60	37.5
43	60	39.5
44	50	25.5
46	60	40.5
48	60	43.5
50	60	47.5
52	60	47.5
54	63	50.5
56	50	33.5

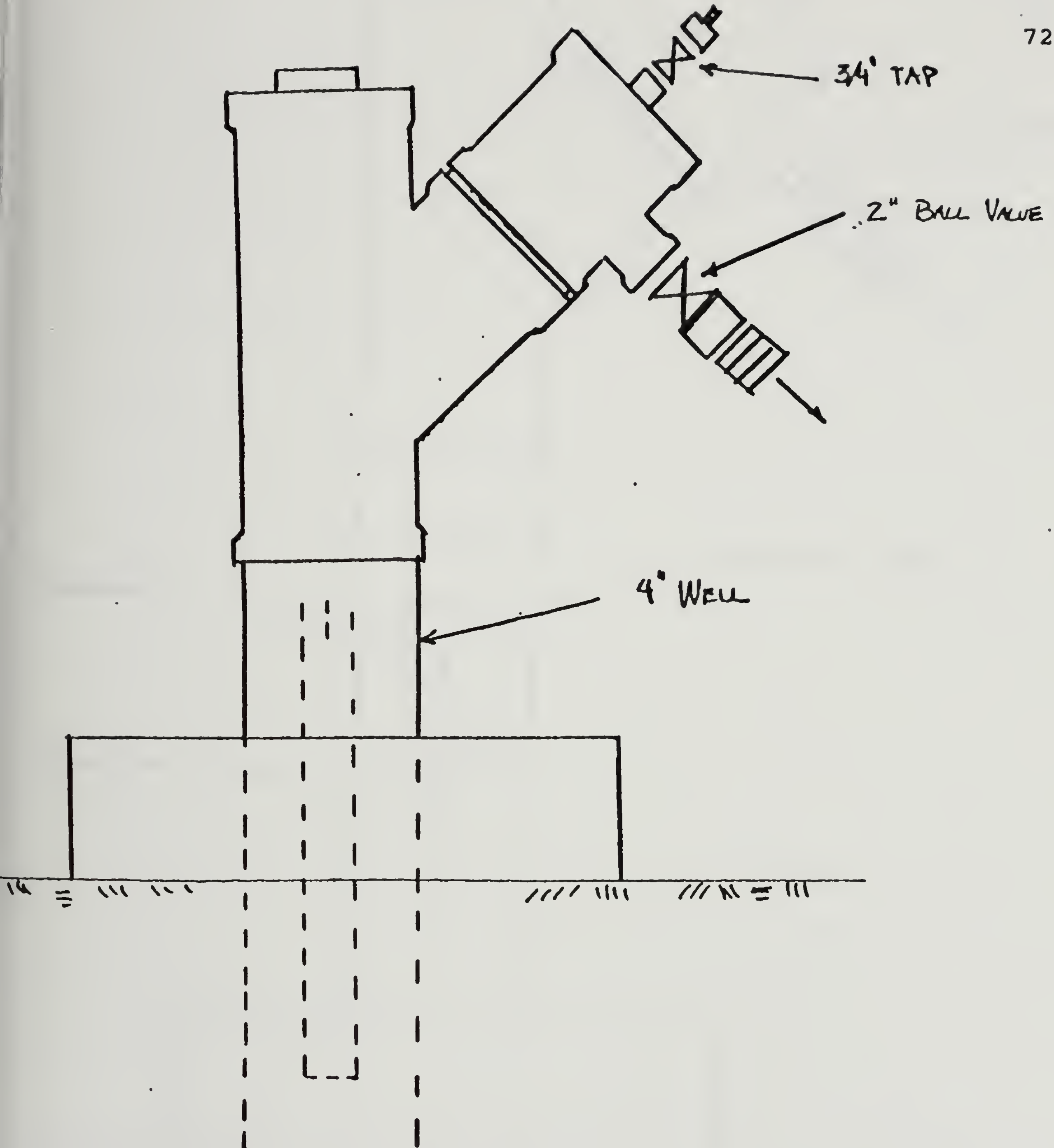

Figure #4-2: Wellhead Detail Prior to Installation of Accu-Flo Device.

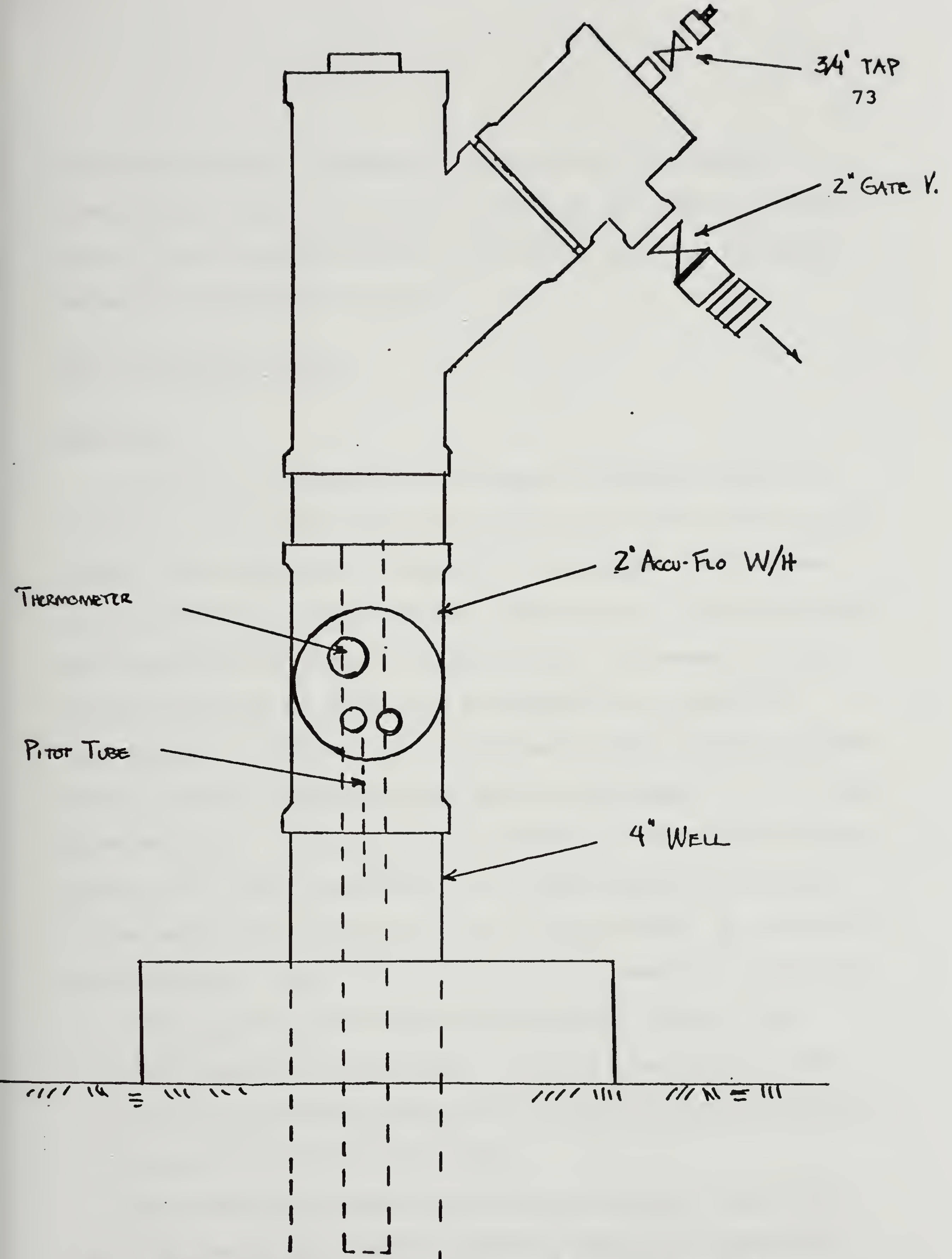

Figure #4-3: Wellhead Detail with Accu-Flo Device.

casing is raised. Presently, there are no wellheads installed on the active cell wells. Final capping of these wells is not scheduled until the final cover is installed, presently scheduled for 1998.

Gas Collection System

Manifold

In 1992, a contract was issued by Alachua County to install a gas collection system for the 30-acre and 11-acre areas. The system was designed to be capable of, in the future, handling flow from the active cell. The system that was installed is shown in Figure 3-15. In summary, the system consists of HDPE pipe configured in a manifold arrangement. Each well is connected to the manifold system via a two inch flexible hose, which is clamped to a two inch HDPE stub out. The stub out connects to a four inch lateral which is in turn connected to an eight inch header which loops around the entire 30- and 11-acre site. At the end of each lateral, there is an in-line valve used for isolating the laterals from the rest of the system. Note: The manifold system has a 10-inch stub out (located near the flare) for the future connection to the collection system to be installed in the 27-acre area.

The manifold header is sloped so that any condensate from the saturated landfill gas will drain to a specific location for processing and treatment. There are two such

locations in this system. One is located at the southeast corner of the site. From here, the leachate is pumped via a three inch PVC pipe into the leachate collection system of the 27-acre lined cell. The other is located beneath a condensate knockout drum just before the blowers. This drum helps remove as much moisture as possible from the gas stream before it passes through the blowers. The condensate collects in a sump and then is pumped to the leachate treatment facility.

<u>Blowers</u>

The system consists of three 25 hp, 3,550 rpm multistage centrifugal blowers connected in series to the manifold piping network. Each blower can be run independently and has a maximum flow capability of 1,100 scfm. A 10-inch butterfly valve is located upstream of the blower intakes, so flow can be throttled. The system is designed to handle a total flow of 2,360 scfm (See Appendix B).

<u>Flare</u>

Flaring is the present method used to treat the extracted landfill gas. The system design incorporates a series of controls which automatically shut down the system if problems develop. One of these controls is a low-temperature control. Another is a flame detector. If for any reason either of these controls fail, the other compensates and shuts the system down. On start up, a pilot

flame is used to bring the flare tip up to temperature. Once the tip is hot, an in-line valve is automatically opened and the blowers are started. The pilot then ignites the landfill gas and the system stays operational until the flame is extinguished. Causes of the flame being extinguished include:

- methane gas concentration dropping below 25 percent;
- the wind blowing the flame out.

If either happens, the blowers shut down, the in-line valve closes and an automatic preset timing sequence is initiated. After a period of time, the ignition sequence described above begins again. Note: The automatic operation can be superseded on this system. Figure 4-4 is a picture of the actual flare and blower system.

Active Tie-in

During the course of this project, consideration was given to attempting to collect the gas being generated from the active 27-acre cell. A design to temporarily connect the existing gas wells to the manifold system was developed. This was modified to reduce interference with daily operations of placing solid waste. A system was designed to collect gas from the leachate collection lines. It was observed that substantial pressures were generated in these lines from gas migration to these lines. A final design connected the leachate collection system's main clean-out

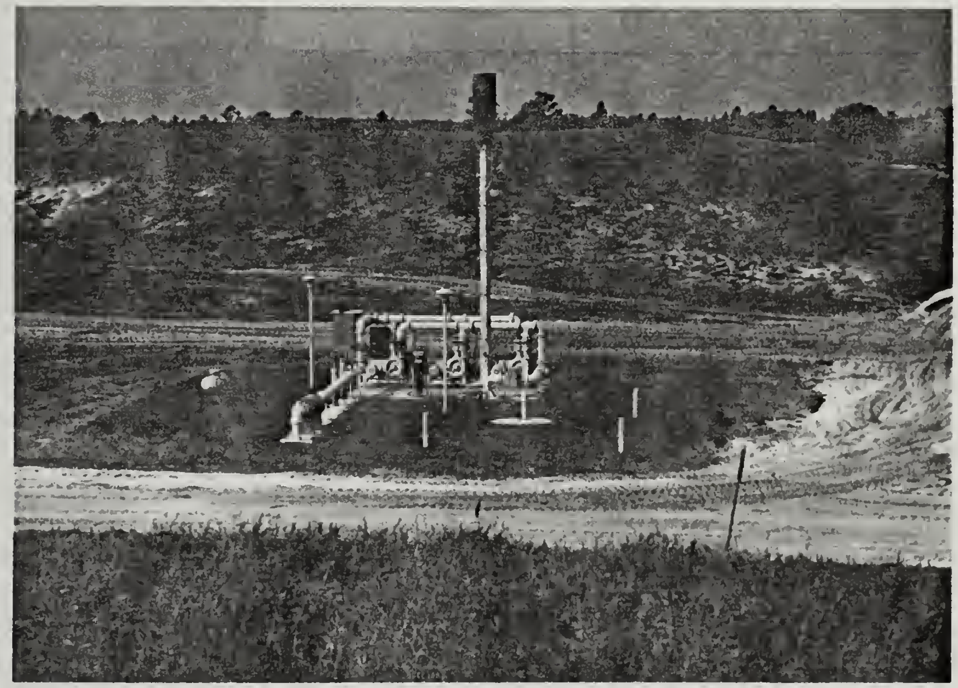

Figure 4-4: Picture of Flare System in Operation.

line to the manifold. A connection at this point was the most cost effective, efficient and least disruptive means of collecting gas from the active cell.

The eight inch clean-out line was connected from the manifold to a two inch stub out of well #46. After it was operated for a period of time, an evaluation of the gas collection data resulted in the design being modified. A system which allowed for two connections to the manifold system at wells #45 and #46, and an increased size of one of the clean-out connecting lines from two inches to four inches was installed. Results are discussed in Chapter 5. Figure 4-5 is a picture of the installation of the revised design. Further investigation revealed that these connections were limited by the two inch HDPE stub-outs. Therefore, a design incorporating a four inch line was developed and installed. Figure 4-6 is a picture of this design installed. Note: The overall goal of this active cell connection was to use the existing system to collect the maximum amount of gas possible. At the same time, every consideration was given to limiting the disruptions to daily operations. A further design consideration was to maintain gas collection with minimum oxygen concentrations.

Figure 4-5: Picture of Active Cell Leachate Clean-out Line Tie-in.

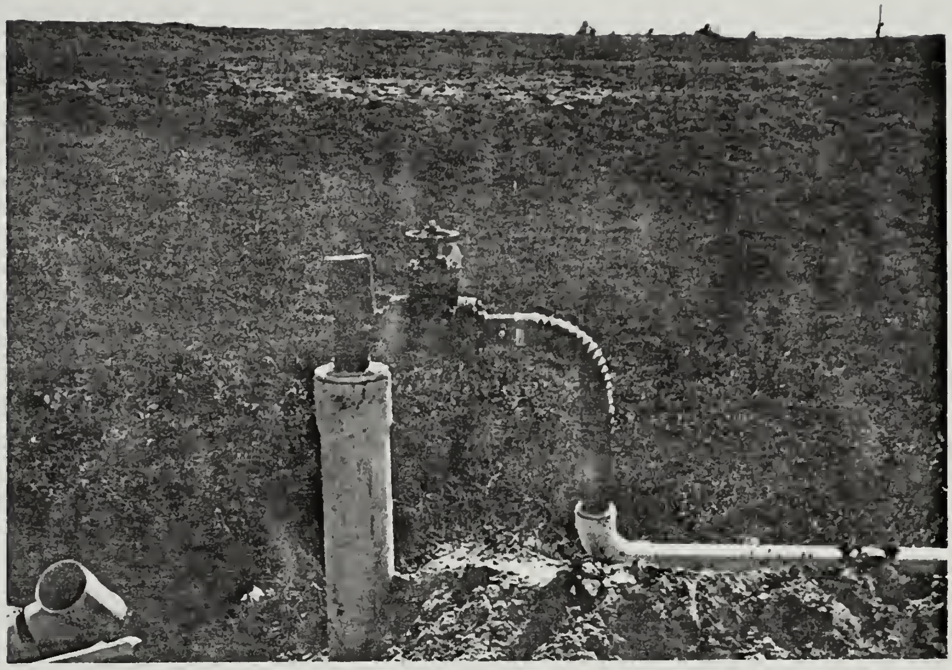

Figure 4-6: Picture of the Actual Installation at the Clean-out Line (Final Configuration).

HIL Tie-in

While gas was extracted from the cleanout line, it was observed that gas pressures in excess of 140 inches of water column were exhibited in the horizontal leachate recirculation lines (HIL) being operated in the 27-acre area. In a combined effort with a graduate student working in this area, a design was developed and implemented to connect these HIL lines to the manifold system. Figure 4-7 and 4-8 show the system implemented.

Sampling Methods

At The Flare

Gas quality

Collection of samples for analysis initially involved taking the sample from a port located on the downstream side of the blowers, transporting it back to the laboratory, calibrating the gas chromatograph, and then running an analysis of the gas composition. Appendix C is an outline of the original detailed procedure used to sample gas from the flare station. One of the objectives of this project was to develop a sampling procedure efficient enough to properly optimize the gas quality and quantity to the flare. Real-time changes in the system needed to be implemented. As a result, this very inefficient procedure was modified.

Figure #4-7: Picture of the Horizontal Injection Lateral Gas Collection System.

Figure 4-8: Picture of the Horizontal Injection Lateral Gas Collection System Tie-in.

Based on recommendations made during the course of this study, Alachua County purchased a Landtec, Inc. (Landfill Control Technologies, Commerce, Ca.) GEM-500 field gas analyzer. This meter allowed for immediate analysis of the gas quality. The procedure set up for the use of this meter is also outlined in Appendix C.

Pressure, Temperature and Flow

Intake pressure was monitored from a pressure gauge located approximately 15 feet upstream from the blower intake. Total flow and temperature were recorded with a Fluid Components, Inc. model GF90 mass flowmeter. This meter calculated flow and reported its output at standard conditions. Standard conditions (scfm) is the flow if the temperature was 60°F and 14.7 psia. Included on this meter was a temperature gauge and a flow totalizer. Weekly readings were logged.

At The Wells

Gas quality

Gas concentrations at the wells in the 11- and 30-acre sites were measured using the Landtec meter. The intake hose for the unit was inserted into the sample port shown (see Figure 4-2). The intake pump was turned on, the gas was analyzed and the concentrations reported. After the installation of the Accu-Flo wellheads (see Figure 4-3),

samples were obtained by connecting the hose barb to the static pressure port on the wellhead.

Pressure and Flow

Pressure initially was measured by connecting a four foot glass manometer to the sample port in Figure 4-2 by a piece of "Tygon" tubing and hose barb fitting on the stubout. The sample port valve then was opened and the pressure recorded as inches of water column.

Flow was calculated by a microprocessor contained in the Landtec meter, based on the pressure differential and the gas temperature. The meter was connected to the Accu-Flo wellhead static and impact pressure ports (see Figure 4-3). The differential then was fed into a preprogrammed equation and the standard flow was reported.

In the 11-acre area, there were two monitoring wells placed in a radial pattern around well #39 (see Figure 3-5). One well was 50 feet to the south the other was 116 feet to the south. These wells were installed with the intention of obtaining data to determine the radius of influence for the wells in the 11-acre area based on a given wellhad vacuum. Pressure data was collected at given wellhead vacuums.

Leachate Levels

Leachate levels in the waste located in the 30- and 11-acre areas were recorded. The procedure involved removing the four inch cap on the wellhead, dropping a pre-chalked

measuring tape to the bottom of the well, recording the level to which it was dropped, removing the tape from the well, and noting the level at which the leachate had saturated the chalk on the tape. From these data, the well depth and the leachate water table was determined.

A portion of this study was aimed at determininghow much accumulated leachate could be removed from the waste by drawing a vacuum at the wellheads. The procedure for this involved setting up the wellfield so that the total flow was coming from only a few wells. With the blowers on at a high pump rate, gas was extracted for an extended period of time. The amount of gas extracted over this period was totaled as well as the vacuum attained and the leachate levels were remeasured. Based on these data, a calculation was made to determine the volume of leachate removed.

Leachate Pumped

As a backup to the leachate level monitoring, data was collected on the duration that the two gas collection system condensate sump pumps were operated over the period of drying. Based on the data and characteristics of the sump pumps, a quantity of leachate removed could be calculated. The meter used to monitor the time of operation of the pumps measured in tenths of an hour.

CHAPTER 5
RESULTS AND DISCUSSION

Initial Set-up

In November 1992, a landfill gas collection system for the Alachua County Southwest Landfill was installed and activated. This system, designed by CH2M-Hill, initially was set to collect gas from all the wells in the 30-acre section (operational fill from 1972 to 1985), and all the wells from the 11-acre section (operational fill from 1985 to 1988) at a total flow rate in excess of 1,000 scfm. During the initial three months the system was operated, it was observed by the landfill staff that the blowers for the system appeared to cycle on and off. Otherwise, no other data was collected.

In February 1993, this study on the collection system began. Samples of the gas were collected from the downstream side of the blowers, just prior to the flare. Analysis of the gas for CH_4, CO_2, N_2, and O_2 concentrations, which initially were conducted using a Gas Chromatograph/Thermal Conductivity detector, revealed that the gas was 48 percent N_2/O_2 and only 28 percent CH_4. The high concentration of N_2/O_2 indicated that air was being drawn into the system. Therefore, the blowers for the collection system must have been withdrawing gas at a higher

rate than it was being produced or the system had air leaks. One goal of this study was to identify those areas where air was entering the system.

Approach

This project was carried out in five phases. In Phases I and III, the 11- and 30-acre areas were balanced. Balancing was necessary to maximize the flow of methane from these areas. Once balanced, the flow data was utilized in Phase V to determine the average rate of decay of the biodegradable portion of the MSW in these areas.

Phase I was an attempt to balance the wellfield by monitoring the vacuum at each of the wellheads and the gas quality at the flare and then removing those wells determined to be non-producers. Balancing a wellfield entails configuring the system such that all wells in the system have an induced wellhead pressure such that the methane flow is maximized and the air introduction is minimized. The only capability for controlling flow was to either throttle the main blowers, or throttle the individual wells. Note: An attempt was made to use the valves on the manifold laterals (Figure 3-15), but it was determined that this approach was not practical as these wells were buried, difficult to access and cumbersome to operate.

The original location available to measure gas flow and quality was at the blowers. With this setup, small changes

to the wellfield system were not immediately apparent from this point. Over the course of Phase I, the wellfield pressures were adjusted to identify which areas were producing gas. These will be discussed later.

Phase II of this study estimated the volume of gas being produced from the 27-acre area. Calculations were made on the quantity of gas escaping from the surface of the landfill and information was collected on the volume of gas that could be extracted from the active cell.

The gas extraction involved connecting the active cell leachate collection clean-out line to the flare system and monitoring the results. Three different configurations were used to collect gas from this point. Consideration was given to providing a connection that used the existing system as much as possible and interfered the least with the daily landfill operations.

In Phase III a further effort was made to quantify and maximize the volume of gas being produced in the 11- and 30-acre areas. This involved modifying the existing wellheads so that better control and more immediate results could be observed from the system adjustments. The existing ball valves on the 11-acre wellheads were replaced with gate valves. Additionally, Accu-Flo wellheads from Landfill Controls Technologies, Inc. which provided the capability to monitor flow, temperature and gas quality at the well were installed. With the new wellhead configuration (see Figure

4-3), another attempt was made at balancing the system. An effort was also made to determine the 11-acre area wells radii of influence for various wellhead pressures.

Phase IV involved using the gas collection system to remove ponded leachate from the 30-acre section. The blowers were set at a high rate, while drawing gas from only a few wells with ponded leachate present (Shank, 1992). Leachate levels were measured in the wells prior to pumping. Based on the level in the well and an assumed MSW porosity of 0.30, an estimation of the quantity of ponded leachate was made. After the area had been pumped for a period of time, leachate levels were remeasured. The difference between the estimated quantity of leachate before and after was calculated. An estimation then was made of the quantity and rate at which leachate was removed.

Phase V used the data obtained in the earlier phases as input to the Scholl Canyon Landfill Gas Kinetic Model (Schumacher, 1983) to determine half-life of the biogradable portion of the deposited MSW. From these values, the quantity of gas still available from the ACSWLF for use in a waste-to-energy conversion process can be determined.

Phase I

The first portion of this phase was to determine the gas quality at the flare with blowers running full (1,000 scfm) with all wells open. The gas quality measured was:

CH_4 = 28%
CO_2 = 24%
O_2 & N_2 = 48%

The flare flame was deep blue (indicating an oxygen-rich mixture) and the system cycled on and off, continuously.

Flow to the blowers was reduced to 500 scfm while pumping on all wells. The system was inspected for air leaks. Some air leaks were found at the wellheads where connections were loose. These were fixed. The immediate gas quality results were as follows:

CH_4 = 38%
CO_2 = 32%
O_2 = 1.2%
N_2 = 28%

The high N_2 content indicated there was air still being drawn into the system. The N_2/O_2 ratio indicated that some of the O_2 had been utilized by the bacteria. Methane concentrations appeared to go up as a result of the methanogenic bacteria bouncing back from the previous toxic oxygen rich environment. The system was allowed to stabilize at 500 scfm for one month. The gas quality measured was:

CH_4 = 43%
CO_2 = 32%
O_2 = 1.5%
N_2 = 22%

The volume of air being drawn into the system was reduced, but a high N_2/O_2 ratio remained.

Pressures at all wells were then measured with blowers set at 500 scfm. Table 5.1 is a list of the pressures observed. The average pressure was 1.5 inches of water

Table 5.1: Pressures observed in the 11 and 30-acre wells in March 1993 with all well valves fully open.

Gas Vent	Vacuum ("H2O)		Gas Vent	Vacuum ("H2O)
1	1		29	1.2
2	0.8		30	2
3	0.8		31	1.2
4	0.5		32	1.3
5	0.6		33	1.8
6	0.6		34	1.2
7	1		35	1
8	1		36	1.8
9	0.4		37	1.6
10	1		38	1.6
11	1		39	1.6
12	1.2		40	1.8
13	1.4		41	1.2
14	1.1		42	0.6
15	1		43	1.4
16	1		44	1.4
17	1		45	2
18	N/A		46	2
19	1		47	1
20	1.6		48	2
21	1.6		49	1.8
22	1.4		50	1.4
23	1.3		51	1
24	1.8		52	1.4
25	1.6		53	1.4
26	2		54	2.2
27	1.2		56	0.4
28	1.8			

(vacuum). The variations in the wellhead pressures were a result of the pressure loss in the collection system between the well and the blowers.

The next step was to close wells #1-25, and 35 in the 30-acre area. Results of Manley's (1992) project indicated that these wells were suspected to be non-producing wells. The same flow of 500 scfm was maintained. The pressure at all wells flowing to the flare (wells #26-34 and 36-56) was remeasured. Because the same quantity of flow was being extracted and the number of wells being drawn from was reduced, the average pressure changed to 7.0 inches of water (vacuum). Meanwhile, the pressure on the closed wells in the 30-acre area was also monitored. Positive pressure was observed only in the northern most wells (#19, 20, 21, 22, and 23). The highest pressure observed was 0.3 inches of water (positive). The other closed wells (#1-25 and 35) in the 30-acre area (except well #8) were at 0.0 inches of water pressure. Table 5.2 lists the pressures observed. The gas quality at the flare with this arrangement was as follows:

CH_4 = 52%
CO_2 = 39%
O_2 = 1.2%
N_2 = 7.5%

The flare flame was now yellow, indicating a fuel rich mixture. The N_2/O_2 ratio was much lower and the N_2 plus O_2 percentage was much lower indicating that much of the air

Table 5.2: Pressures observed in the 11- and 30-acre wells in March 1993 with 30-acre well valves (1-25 and 35) closed.

Gas Vent	Pressure ("H2O)		Gas Vent	Pressure ("H2O)
1	0		29	-6.3
2	0		30	-6.3
3	0		31	-6.4
4	0		32	-6
5	0		33	-6.4
6	0		34	-5.15
7	0		35	0
8	0.2		36	-6.5
9	0		37	-6.6
10	0		38	-6.9
11	0		39	-6.95
12	0		40	-6.9
13	0		41	-6.8
14	0		42	-7
15	0.05		43	-7.7
16	0.05		44	-7.5
17	0		45	-7.2
18	N/A		46	-7.4
19	0.15		47	-5.3
20	0.3		48	-7.2
21	0.2		49	-7.2
22	0.1		50	-6
23	0.1		51	-7
24	0		52	-6.2
25	0		53	-6.8
26	-6		54	-6.8
27	-5.6		56	-7.1
28	-5.6			

previously being drawn into the system had been from the 30-acre area. Wells #27, 29, 31, and 32 then were removed from the collection system while pumping at the same rate. All wells previously turned off, remained off. This was done to determine if the methane concentration could be further improved. The gas quality at the flare with this wellfield configuration was:

CH4 = 50%
CO2 = 37%
O2 = 2%
N2 = 11%

An increase in the O2 and N2 concentrations and a decrease in the CH_4 concentration were seen. By removing producing wells from the system, while at the same time maintaining the flow rate, the other connected wells (26, 28, 30, 32-34, and 36-56) were now being overdrawn.

Wells #9, 10 ,15, 16, 21, and 22 were turned on, while leaving all other wells at the 30-acre site off (except wells #26, 28, 30, 33, and 42). This was done to determine the effect of using these interior wells to relieve the small positive pressure building in the 30-acre area. When the pressure in the 30-acre site wells was remeasured, the pressure reduced to 0.0 inches of water. The gas quality at the flare with this wellfield configuration was:

CH4 = 43%
CO2 = 32%
O2 = 4%
N2 = 21%

It appeared that opening these six interior wells reduced the pressure buildup, but also reduced the quality of the gas at the flare. The vacuum induced at the well head with this setup was measured and is shown in Table 5.3.

These six wells were then turned off and the gas quality returned to its previous values.

CH_4 = 51%
CO_2 = 38.5%
O_2 = 1.5%
N_2 = 9%

This was a strong indication that gas was no longer being produced in the majority of the 30-acre area (wells #1-25 and 35). By pumping on them, air was drawn into the system.

The system was allowed to stabilize for two months at 500 scfm and the gas quality was remeasured. No major changes in the gas quality were observed over this period.

CH_4 = 52%
CO_2 = 37.5%
O_2 = 1.5%
N_2 = 9%

The blower flow rate was then reduced to 200 scfm. This was done to see if the oxygen and nitrogen levels could be decreased further while increasing the methane concentration. The gas quality with the blowers at the lower flow rate did improve, but the system began to cycle on and off.

Table 5.3: Pressures observed in the 30-acre wells with 30-acre wells #9,10,15,16,22, and 26-56 open.

Gas Vent	Valve Status	Pressure ("H2O)	Gas Vent	Valve Status	Press ("H2O)
1	closed	0	29	open	*
2	closed	0	30	open	*
3	closed	0	31	open	*
4	closed	+0.05	32	open	-4.5
5	closed	0	33	open	*
6	closed	+0.05	34	open	*
7	closed	0	35	closed	+0.1
8	closed	0	36	open	*
9	open	-3.5	37	open	*
10	open	-3.5	38	open	*
11	closed	-0.4	39	open	*
12	closed	-0.05	40	open	*
13	closed	-0.05	41	open	*
14	closed	-0.4	42	open	*
15	open	-3.5	43	open	*
16	open	-3.7	44	open	*
17	closed	-0.4	45	open	*
18	closed	0	46	open	*
19	closed	+0.15	47	open	*
20	closed	+0.1	48	open	*
21	closed	-0.1	49	open	*
22	open	-3.5	50	open	*
23	closed	-0.4	51	open	*
24	closed	0	52	open	*
25	closed	*	53	open	*
26	open	*	54	open	*
27	open	*	56	open	*
28	open	*			

* = Pressure not measured.

CH_4 = 54%
CO_2 = 39%
O_2 = 1.5%
N_2 = 6%

Even though the rate of 200 scfm was reported by the manufacturer to be within the design flow range for this system, it was determined that the wind was blowing out the flame, which resulted in a system shut down.

The pressures and gas qualities in the 30-acre area wells that were isolated from the collection system were monitored for one month. Table 5.4 depicts the pressures measured and the gas quality at each well. The average pressure observed was 0.5 inches of water (positive), with the maximum pressure being 0.8 inches of water (positive). These pressure increases over a month period are relatively small when compared to the pressure increases expected from a productive area. Therefore, based on these data, the data collected earlier in this study and the information provided by Manley (1992), it was concluded that the MSW in the older portion of the 30-acre site (#1-25 and 35) was no longer producing gas. The wellfield required a configuration that would primarily draw gas from the 11-acre area and the northern-most portion of the 30-acre area.

Figure 5-1 is a graphic of the total pumped flow at the flare over this phase of the project. Figure 5-2 is a graphic of the total methane and oxygen flow rates for the same time period. Table 5.5 and 5.6 are the data for these figures, respectively. The methane flow only increased from

Table 5.4: Pressures observed in the 30-acre wells in June 1993 with 30-acre well valves closed for one month.

Gas Vent	Pressure ("H2O) after one week	Pressure ("H2O) after two weeks	Pressure ("H2O) after one month
1	0	0.1	0.2
2	0	0.1	0.2
3	0	0	0.1
4	0	0	0.1
5	0	0	0.1
6	0	0	0.1
7	0	0.1	0.2
8	0.2	0.3	0.5
9	0	0.15	0.4
10	0	0.15	0.4
11	0	0.3	0.6
12	0	0.2	0.5
13	0	0.2	0.5
14	0	0.2	0.5
15	0.05	0.2	0.5
16	0.05	0.3	0.6
17	0	0.25	0.6
18	0	0.25	0.6
19	0.15	0.2	0.4
20	0.3	0.5	0.8
21	0.2	0.4	0.6
22	0.1	0.3	0.6
23	0.1	0.3	0.6
24	0	0.3	0.8
25	0	0.3	0.8

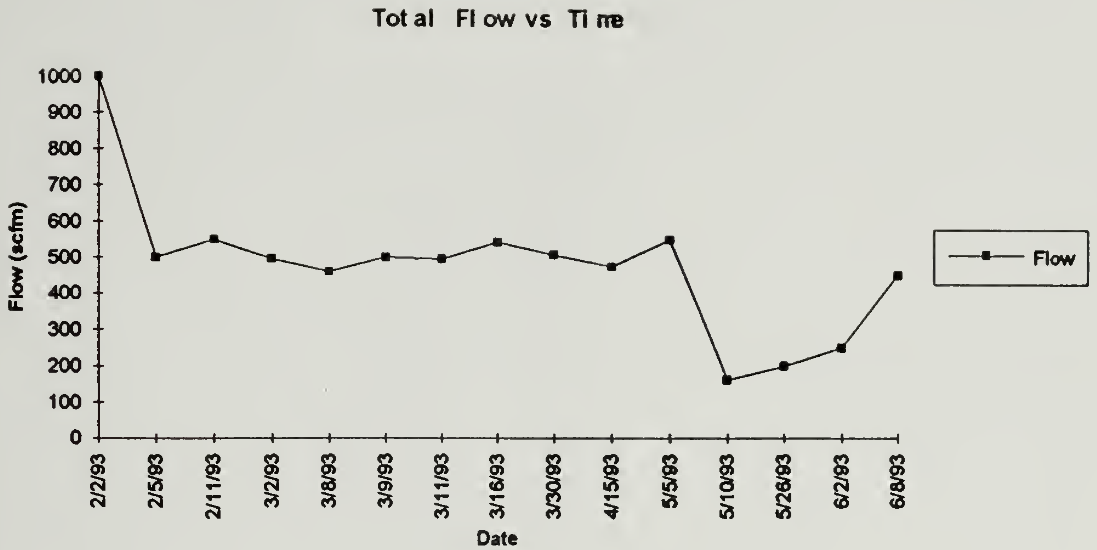

Figure 5-1: Total Flow at Flare During Phase I.

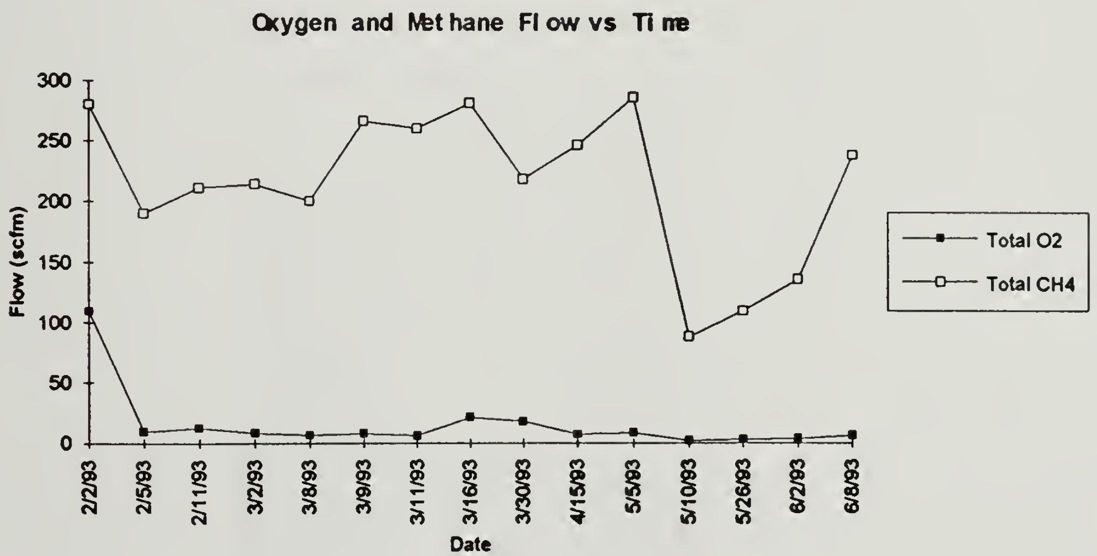

Figure 5-2: Total Methane and Oxygen Flow at Flare During Phase I.

Table 5.5: Total Flow Data for Phase I.

Date	Flow (scfm)
2/2/93	1000
2/5/93	500
2/11/93	550
3/2/93	496
3/8/93	459
3/9/93	500
3/11/93	496
3/16/93	542
3/30/93	506
4/15/93	474
5/5/93	550
5/10/93	163
5/26/93	200
6/2/93	250
6/8/93	450

Table 5.6: Methane and Oxygen Flow Data for Phase I.

Date	Total O2 (scfm)	Total CH4 (scfm)
2/2/93	110	280
2/5/93	9.5	190
2/11/93	12.7	211
3/2/93	8.4	214
3/8/93	6.9	200
3/9/93	8	266
3/11/93	6	260
3/16/93	21	281
3/30/93	17.7	218
4/15/93	7.1	246
5/5/93	8.3	286
5/10/93	2	88
5/26/93	2.8	110
6/2/93	3.5	136
6/8/93	6.3	238

280 scfm to 286 scfm, but the oxygen flow rate decreased from 110 scfm to 11 scfm. Appendix D depicts the wellhead pressures that were measured for the given wellfield configuration over this phase of the project.

Phase II

Prior to this portion of the project, Alachua County officials had been receiving numerous complaints from nearby residents about the odor coming from the landfill. Observations by Manley (1992) and Reinhart (1993) that a great quantity of gas was escaping from the active cell led to the conclusion that the odor was coming from that area. Therefore, an attempt was made in this project to collect as much gas as possible from the active area while constrained by the use of the existing system and avoiding interference with the landfill's daily operations.

The landfill staff reported that high pressures were seen in the leachate collection system clean-out laterals causing the caps to be blown off (no measurements were recorded). Therefore, the leachate collection system's eight inch clean-out line (as shown in Figure 5-3) was connected to the gas wells in the 11-acre section. This connection would collect gas that had migrated into the leachate collection system. The first problem was to locate this clean-out line. After numerous attempts to locate it by hand, landfill operators found it with a backhoe. Once

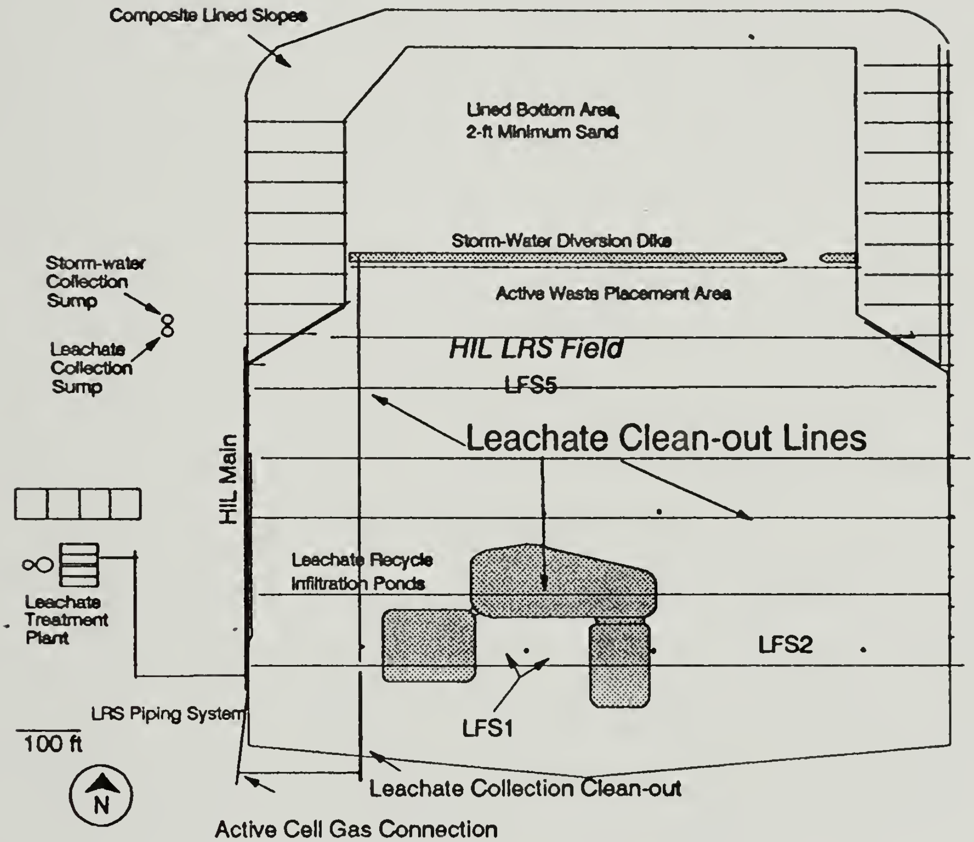

Figure 5-3: 27-Acre Leachate Collection Clean-out Lines.

the line was located, it was discovered that it was completely plugged by sand. The line was cleared using the County's water cannon. The next step was to determine how to connect the line to the blowers. Figure 5-4 is a sketch of the initial system used. The clean-out line was reduced down from eight inches to two inches. Then, via 30 feet of flexible hose, it was connected to a two inch ball valve. The ball valve was connected to a two inch by two inch tee located at wellhead #45.

This system was allowed to operate for a period of 8 weeks. During this period, the pressure at the clean-out lateral closest to the eight inch conection was monitored. A flow rate of 65 scfm was maintained with this connection. It was observed that this was only a small portion of the gas from the active cell as the leachate collection laterals in Figure 5-3 were still found to have a positive pressure. The pressure, with only one hookup, was 0.3 inches of water (positive). The following was the gas quality collected at the clean-out:

CH_4 = 57%
CO_2 = 43%
O_2 = 0%
N_2 = 0%

The second configuration involved a second connection to the manifold system. An eight inch tee was installed on the clean-out line and a 2 inch hose was run to well #46. Even though the total flow from the clean-out line did

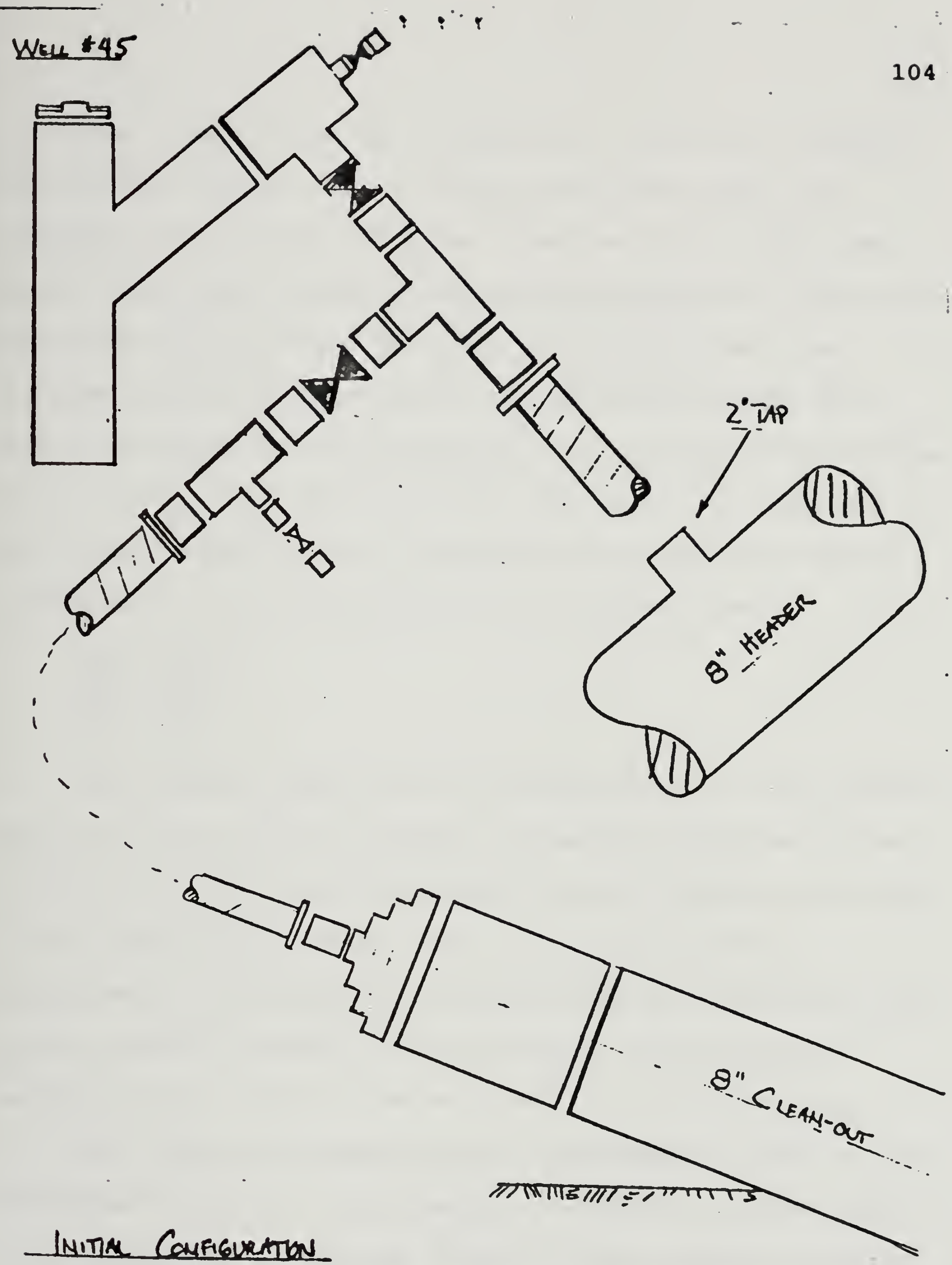

Figure 5-4: Initial Leachate Clean-out Line Connection.

increase from 65 scfm to 130 scfm, the frictional pressure drop across the two inch flexible hoses was great and resulted in 20 inches of water pressure loss. After one week, the 2 inch flexible hose was replaced with a four inch PVC pipe in an attempt to reduce this loss. The flow through this line increased by approximately twice that which was being drawn through the two inch line from 65 scfm to 130 scfm. The total flow from the clean-out line now was 200 scfm. Figure 4-5 is a picture of the system that was installed. The gas quality at the clean-out was:

CH_4 = 56%
CO_2 = 44%
O_2 = 0%
N_2 = 0%

Even though there were two connections, it was observed that only 0.25 inches (vacuum) was being introduced at the clean-out. The pressure at the clean-out lateral, with the 2 inch and 4 inch hookups, was 0.1 inches of water (positive). Additionally, in the Horizontal Injection Lines (HIL) used for leachate recirculation, gas pressures in excess of 150 inches of water (positive) were observed.

The clean-out connection was redesigned so that it was connected directly to the manifold collection system with a 4 inch capacity as opposed to the 2 inch capacity at wells #45 and #46. It was felt that a direct four inch gas line could draw more gas from this point to the flare. Figure 5-5 is a picture of the final clean-out line connection. Note: The system has been constructed so that the capacity

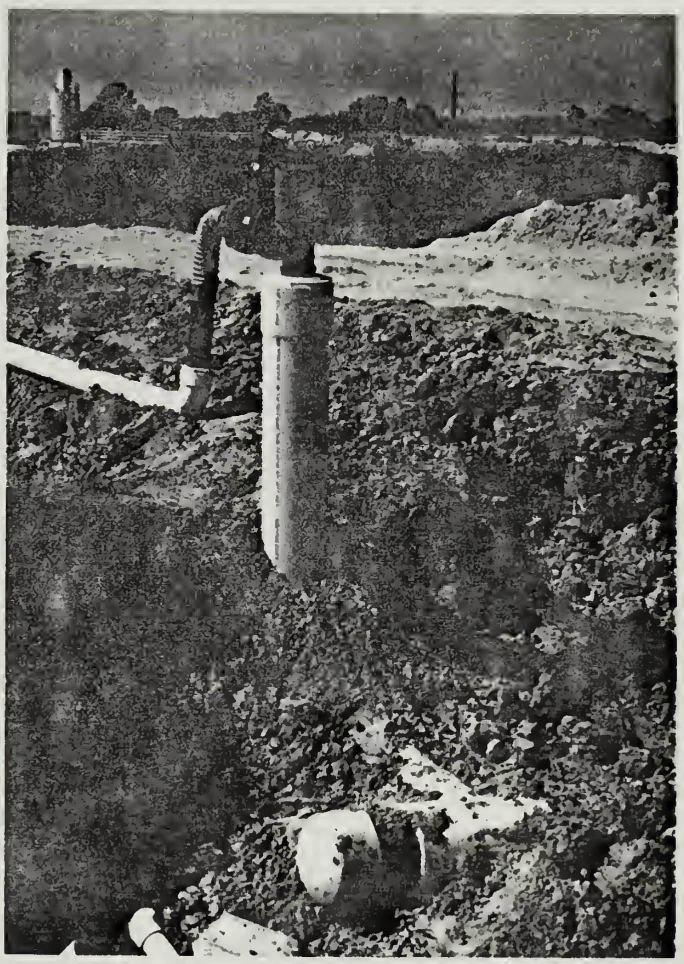

Figure 5-5: Picture of Leachate Clean-out Gas Line Connection.

can be increased to an eight inch line in the future, if desired. Additionally, a system was also designed and installed to connect the HIL to the manifold system using four inch gas lines. Unfortunately, it was not operational prior to the completion of this study, so no data is reported here. Figure 5-6 is a picture of the HIL gas collection system. With this system in place, the quantity of gas that can be collected from the active cell should increase dramatically.

Once the 4 inch line system was connected, flow from the active cell clean-out increased from 200 scfm to 535 scfm. Figure 5-7 and Table 5.7 represent the total methane flow over time for the gas drawn from the active cell clean-out. The quality of the gas coming from this point remained free of air:

CH_4 = 53%
CO_2 = 47%
O_2 = 0%
N_2 = 0%

The next area examined was the quantity of methane escaping from the active cell through the landfill surface. Research has been conducted by the University of Central Florida on a portion of the ACSWLF surface. Reinhart (1993) concluded that the methane surface emission rate from this area was 0.00035 scfm/sf. Presently, the landfill is two-thirds full and has a surface area of approximately 785,000 sf. This equates to a surface emission rate of 275 scfm of methane. The northern face of the landfill also has gas

Figure 5-6: Picture of Horizontal Injection Laterals Gas Lines in Active Cell.

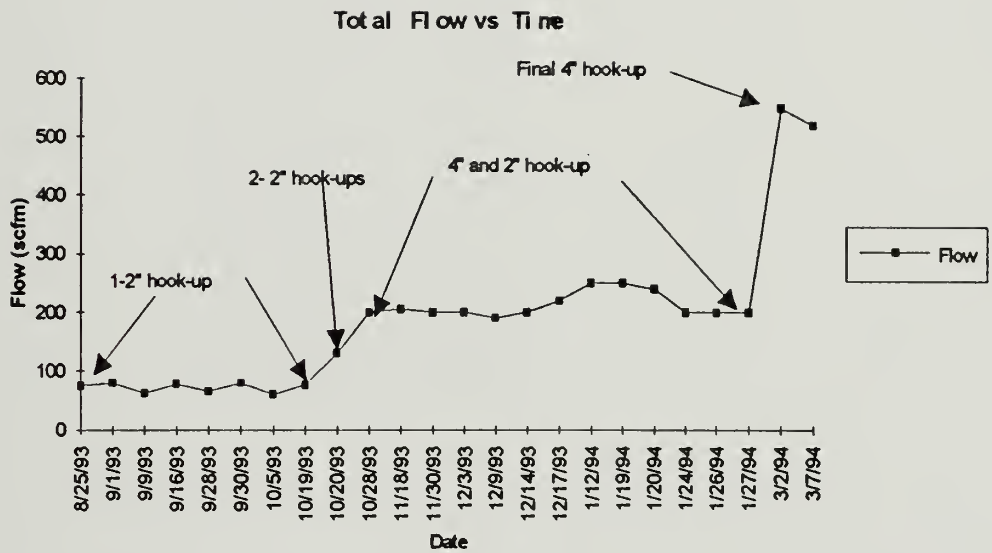

Figure 5-7: Total Flow (CH4, CO2, N2, and O2) at the Flare From the Active Cell.

Table 5.7: Total Flow (CH_4, CO_2, N_2, and O_2) at the Flare From the Active Cell.

Date	Flow (scfm)
8/25/93	75
9/1/93	80
9/9/93	62
9/16/93	78
9/28/93	65
9/30/93	80
10/5/93	60
10/19/93	76
10/20/93	130
10/28/93	200
11/18/93	205
11/30/93	200
12/3/93	200
12/9/93	190
12/14/93	200
12/17/93	220
1/12/94	250
1/19/94	250
1/20/94	240
1/24/94	200
1/26/94	200
1/27/94	200
3/2/94	550
3/7/94	520

being emitted from it. The surface area of the face is estimated to be approximately 500,000 sf which translates to an emission rate of 175 scfm. The final area that gas is known to be escaping is through the HIL system. Presently this system is venting gas, but the quantity has not been determined. An preliminary estimation of this quantity will be made in Phase V of this chapter.

Phase III

This phase of the study was an extention of Phase I. During Phase I, the methods used in balancing the system were controlling gas flow by wellhead vacuum and controlling gas flow by wellhead valve position. The technique of contolling gas by wellhead vacuum relies on the relationship of pressure to flow for a given well. Because of the square root relationship between flow and pressure, well adjustments by vacuum pressure can be deceptive. The technique of controlling gas by valve position is also deceptive. Unless the valve handle is pre-calibrated for given flows or pressures, this method is unreliable (Landtec Wellhead Manual, 1992). The ball valves originally installed in the 11- and 30-acre wellfields were not designed for throttling and could not be calibrated. These valves tended to stick, making it very difficult to adjust for small flow changes. Additionally, the vacuum induced at the wellhead varied considerably from well to well even

though the valves appeared to be set to the same opening. Therefore, the first action was to replace all the ball valves in the 11-acre area and the northern-most lateral of wells in the 30-acre area (#26, 28, 30, 33, and 42) with gate valves. Table 5.8 depicts the variation of wellhead pressures with the ball valve handles positioned equally. The use of the gate valves greatly improved the throttling capability.

The second action taken was to install a flow and gas quality monitoring device at each wellhead. The County purchased the Accu-Flo, two inch retrofit wellheads from Landfill Control Technologies, Inc., Commerce, Ca. This device, when used in conjunction with a field gas analyzer discussed previously (also purchased from Landfill Control Technologies, Inc.), provided the capability of determining which wells were being overdrawn or underdrawn. If the gas quality indicated that air was being introduced at the wellhead, the newly installed gate valve was adjusted to reduce the flow. Appendix E describes in detail the operation of the Accu-Flo wellhead and gas analyzer system.

The third action in Phase III was to determine what the radius of influence of the gas wells in the 11-acre wellfield was based on a given wellhead pressures. By setting the wellhead pressure at well #39 to 26 inches of water (vacuum), pressure at the radial monitoring wells A and B (see Figure 3-15) and the gas quality at the

Table 5.8: Pressures observed in the 11 and 30-acre wells and wellhead valve positions.

Gas Vent	Vacuum("H2O)		Valve Position	Gas Vent	Vacuum ("H2O)	Valve Position
1	0		closed	29	1.5	1/4 open
2	0		closed	30	29	1/4 open
3	0		closed	31	6	1/8 open
4	0		closed	32	34	1/4 open
5	0		closed	33	16	1/4 open
6	0		closed	34	3.5	1/8 open
7	6		1/4 open	35	0	closed
8	8		1/4 open	36	3	1/8 open
9	0		closed	37	13	1/4 open
10	0		closed	38	24	1/4 open
11	0		closed	39	10	1/4 open
12	0		closed	40	5	1/4 open
13	0		closed	41	25	1/8 open
14	0		closed	42	2.5	1/8 open
15	0		closed	43	23	1/2 open
16	0		closed	44	12	1/4 open
17	7		1/4 open	45	12	Open full
18	0		closed	46	38	Open full
19	0		closed	47	4	1/4 open
20	5		1/4 open	48	9	1/4 open
21	12		1/4 open	49	22	1/4 open
22	22		1/4 open	50	0.5	1/4 open
23	0		closed	51	9	1/4 open
24	0		closed	52	5	1/4 open
25	0		closed	53	6	1/4 open
26	15		1/4 open	54	5	1/4 open
27	4		1/4 open	56	24	Open full
28	3		1/4 open			

wellheads were recorded. The gas quality at the wellhead indicated that the well was being overdrawn as air was diluting the gas stream.

CH_4 = 52.5%
CO_2 = 40.4%
O_2 = 1.0%
N_2 = 6.1%

The pressure at well A was 4.0 inches of water (vacuum) while the pressure at well B was 0.9 inches of water (positive) indicating that the radius of influence for this induced wellhead pressure was between wells A and B.

The pressure at the wellhead then was changed to 9.4 inches of water (vacuum). The gas quality at the wellhead was:

CH_4 = 57.2%
CO_2 = 42.8%
O_2 = 0.0%
N_2 = 0.0%

indicating that air was no longer entering the gas stream. The pressure at well A increased to 2.7 inches of water (positive). Therefore, the radius of influence had been reduced to less than 50 feet for this wellhead pressure.

Based on these data and a given average well spacing of 180 feet, it was determined that the wellhead pressures needed to be greater than 9.4 inches of vacuum and less than 26 inches of vacuum to ensure that all the gas being generated between the wells in the 11-acre area was collected with no air introduction. This range agrees with

the literature (Tchobanoglous et al., 1993). Because there were only two monitoring wells, the data needed to determine the radius of influence for various wellhead pressures was incomplete.

During this phase, the Alachua County staff requested that all the 30-acre wells, including those which were determined to be no longer producing gas, be opened to the blowers. To accommodate the County's request and still accomplish an accurate balancing of the wellfield, the non-producing wells were opened slightly. An attempt (using the sluggish 30-acre ball valves) was made to provide one inch water (vacuum) at these wells, thereby limiting the potential for drawing air into the system. This arrangement was satisfactory to the County.

After all the wells were opened and the wellhead items installed, an aggressive attempt was made to balance the wellfield and to quantify the volume of gas being collected. First, the active cell connection was closed. Next, initially, the blowers were set to 550 scfm, which was the flow range that had been predicted from earlier data. Table 5.9 lists the gas quality and wellhead pressures prior to the installation of the wellheads. Table 5.10 shows the results of the flow and quality of the gas being drawn from all the wells connected to the system after the wellheads were installed. A total flow of 348 scfm at 47.7 percent methane (166 scfm of methane) was collected from the 11-acre

Table 5.9: Gas Quality and Pressure at the Wells in the 11- and 30-Acre Area Prior to installation the Accu-Flo Wellheads.

Gas well #	CH4%	CO2%	O2%	N2%	Vac ("H2O)
26	57.7	41	0	1.2	1.8
27	57.0	39.0	0	4.0	2.3
28	53.1	38.1	0	9.1	2.8
29	40.4	28.5	5.6	25.1	2.6
30	0.1	0	20.3	79.6	15
31	0.3	0.2	20.2	79.3	15
32	0.2	0.1	20.3	79.4	3.4
33	57.9	36.6	0	5.5	4.4
34	46.2	37.6	0.1	16.4	4.3
36	32.2	36.7	0.9	30.3	9.6
37	54.6	45.4	0	0	11.8
38	53.7	46.3	0	0	12.7
39	48.8	40.0	2.0	9.2	13.6
40	46.2	45.0	0	8.8	24.6
41	54.4	45.4	0.2	0	19.9
42	45.1	37.5	0	17.2	1.0
43	51.0	45.5	0.1	3.4	10.9
44	46.0	40.7	2.3	11.0	15.4
45	52.7	47.3	0	0	11.6
46	50.6	45.7	0.8	2.8	7.1
47	51.1	44.0	0.2	4.0	3.8
48	51.4	45	0.1	3.5	6.0
49	46.0	38.0	2.2	3.8	7.6
50	38.9	36.8	3.4	21.9	6.8
51	53.0	44.4	0.1	2.5	15.6
52	54.0	45.5	0	0.5	15.6
53	40.8	40.7	0	9.5	8.8
54	53.0	46.0	0	1.0	11.4
56	33.3	38.9	0	27.8	9.9

Table 5.10: Gas Flow and Quality from the Wells in the 11-Acre Area Measured with the Accu-Flo Wellheads.

Gas well #	Flow (scfm)	CH4%	CO2%	O2%	N2%	Vac ("H2O)
26	2	59.2	40.8	0	0	4.6
28	17	53.4	39.4	0	7.2	5.8
30	2	60	40	0	0	18.2
33	12	59	38	0	3	21.7
34	58	46.4	38	0.4	15.2	7.6
36	60	36	36.1	0.1	27.8	19.7
37	9	58.7	41.3	0	0	20.6
38	2	57.5	37.3	0.2	5	18.2
39	22	56.5	42.9	0.6	0	18
40	9	57.4	42.6	0	0	11
41	3	54.1	42	1.4	2.5	28.9
42	30	50.4	39.6	0	10	2.4
43	0	51.6	42.1	0	6.3	11
44	0	56.9	42.8	0	0.3	14
45	22	58	42	0	0	23
46	1	53.3	41	1	4.7	20
47	37	55.8	44	0.2	0	6.8
48	2	40.4	37.3	2	20.3	17.5
49	0	36.9	37.2	4.8	21.1	8.9
50	28	43.8	38.5	2.3	15.4	8.2
51	19	56.2	43.4	0.2	0.2	20.2
52	11	58.6	41.4	0	0	9.3
53	12	43.9	39.5	0	16.6	15.3
54	20	57.3	42.1	0.3	0.3	13.4
56	4	34.1	37.6	0	28.3	15.3

area and 208 scfm of 46 percent methane gas (96 scfm of methane) was collected from the northern portion of the 30-acre area. Figure 5-8 and Table 5.11 represent the total methane removed from the 11- and 30-acre wells over this phase of the project.

Phases I, II and III were preliminary measures that were needed to maximize and quantify the volume of gas being produced in the 30-acre, 11-acre, and 27-acre areas. Table 5.12 depicts the final results from these phases that will be used in Phase V, the determination of the average biological decomposition rate of the biodegradable portion of the deposited MSW.

Phase IV

Phase IV of this project examined the feasibility of using a landfill gas collection system as a method of drying saturated MSW. If wet cell technology is incorporated in the future, some efficient method of drying the waste after it has been thoroughly decomposed needs to be developed. The first step in this phase was to identify an area in the gas collection wellfield where the waste was water saturated. Previous research (Shank, 1992) indicated that wells #7, 8, 17, 20, 21, 22 and 32 had leachate present.

The second step involved quantifying the volume of ponded leachate. A sounding tape was dropped into the gas wells in the areas of saturation. This indicated the level

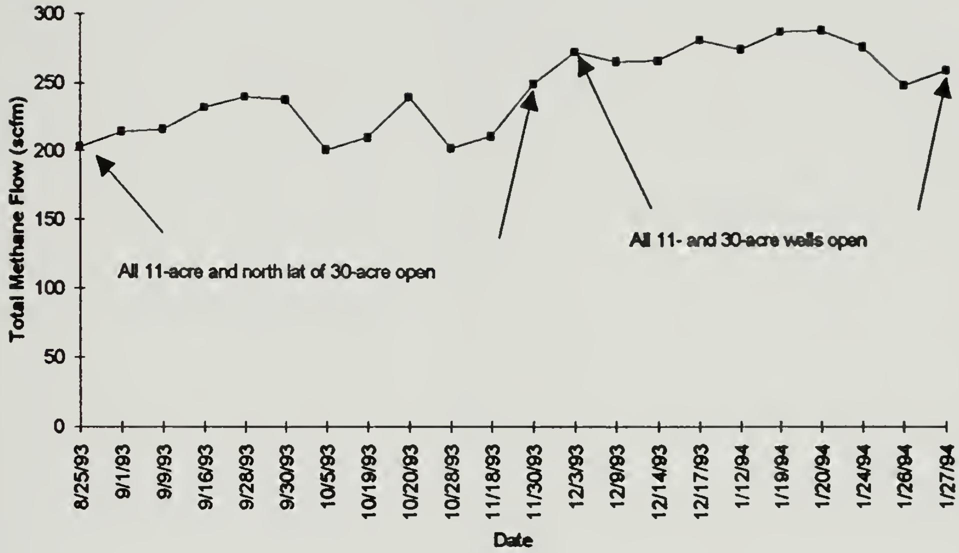

Figure 5-8: Total Methane from 11- and 30-Acre Areas in Phase III.

Table 5.11: Total Methane from 11- and 30-Acre Areas in Phase III.

Date	Methane Flow (scfm)
8/25/93	203
9/1/93	214
9/9/93	216
9/16/93	232
9/28/93	240
9/30/93	238
10/5/93	201
10/19/93	210
10/20/93	240
10/28/93	202
11/18/93	211
11/30/93	250
12/3/93	273
12/9/93	266
12/14/93	267
12/17/93	282
1/12/94	275
1/19/94	288
1/20/94	289
1/24/94	277
1/26/94	249
1/27/94	260

Table 5.12: Final Results from Phases I, II, and III on LFG optimization from the 30-acre, 11-acre and 27-acre Areas.

30-Acre Area	
Non-Producing Wells	1-25, 35
Producing Wells	26-33, 42
Total Flow (scfm)	208
Percent Methane	46
Total Methane (scfm)	96
11-Acre Area	
Non-Producing Wells	none
Producing Wells	34, 36-41, 43-54, 56
Total Flow (scfm)	348
Percent Methane	47.7
Total Methane (scfm)	166
27-Acre Area	
Vol Escaping Surface (scfm)	275
Vol Escaping Wells (scfm)	8
Vol Escaping N.Face (scfm)	175
Vol Collect Clean-out (scfm)	284

of leachate found in the well. Table 5.13 indicates the initial results of these soundings. From the data, an extrapolation of the amount of leachate in the area of the well was made. For the purpose of estimating the quantity of leachate ponded, the following assumptions were made: (1) the MSW below the leachate level found in the wells was completely saturated (i.e. the leachate was not perched within the cell), (2) all ponded leachate in this area is hydraulically connected, and (3) the porosity of MSW was 0.30. By inserting the soundings into the program SURFER, a contour map and estimated volume were calculated. Figure 5-9 depicts the results of this extrapolation. Based on the above assumptions, an estimated quantity of 7.0875 million cubic feet of leachate is ponded in the 11- and 30-acre areas.

The next step was to turn on the blowers at a high rate, while pumping from only a few wells. Wells #7, 8, 17, 20, 21, 22, 30, 31, 32 and 33 were chosen to be the test wells. The gas was withdrawn at a rate of 1,000 scfm for 30 days. After the pumping ceased, the leachate levels in the wells was remeasured. Table 5.14 depicts the levels in the wells immediately after the pumping ceased. Table 5.15 and Table 5.16 are the levels in the wells 30 days and 60 days after the pumping, respectively. On average, 0.5 feet of leachate was removed from the test wells. The data shown in Table 5.16 was input into the SURFER program. Figure 5-10

Table 5.13: Initial Well Soundings Indicating the Level of Leachate Ponded in the 30-acre Site Prior to Pumping.

Well #	Top of PVC Elevation (msl)	Top of PVC to Leachate (ft)	Leachate Depth in Well (ft)
5	108.6	42.8	0
6	104.4	44.2	0.1
7	105.3	32.5	9.5
8	105.2	22.9	17.3
9	114.3	34	0.1
16	117.9	42.4	0.4
17	115.5	37.3	2.6
18	109.8	38.4	3.2
19	112.9	43.8	0.5
20	113.2	24.2	13.4
21	119.5	27.8	12.7
22	123.5	30	9.5
23	124.7	38.4	0.1
29	126.4	41.8	0.4
30	127.5	29.2	16
31	123.8	33.5	6.3
32	115.8	26.2	1.4
33	127.1	30.2	20.5
34	132.1	68.4	0
35	114.3	42.1	0.1
37	134.5	32	0
38	138.8	27	0

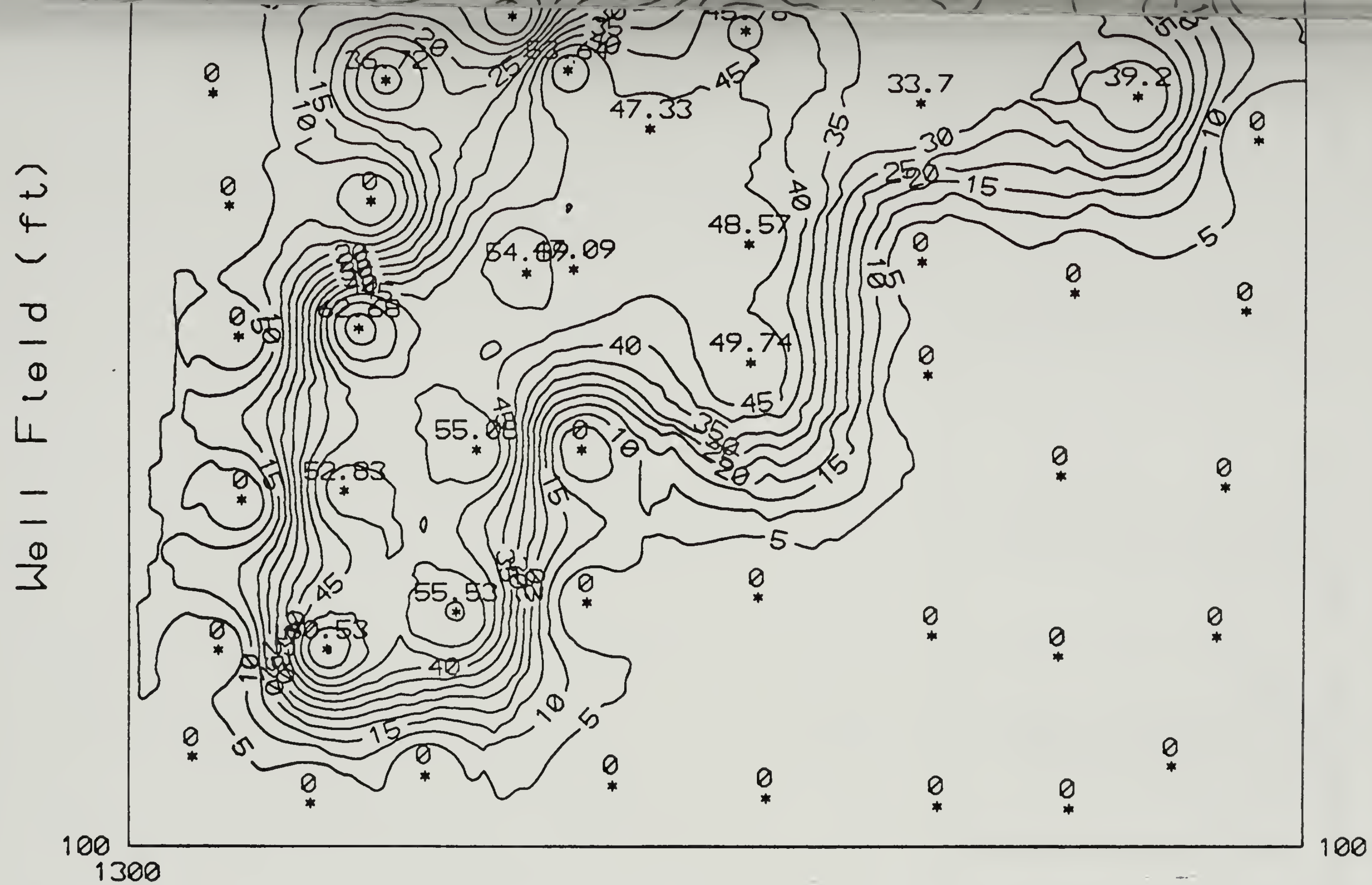

Figure 5-9: Isobaric Plot of the Leachate Levels in the 30 and 11-Acre Wells Before Drying (Feet above Groundwater).

Table 5.14: Leachate Level Changes in the 30-acre wells Immediately After the Drying Procedure.

Well #	Top of PVC Elevation (msl)	Top of PVC to Leachate (ft)	Leachate Depth in Well (ft)	Change of Leachate (ft)
7	105.3	31.6	10.0	+0.9
8	105.2	23.7	16.1	-1.2
17	115.5	38.1	1.6	-0.8
20	113.2	24.7	12.9	-0.5
21	119.5	27.7	12.8	+0.1
22	123.5	30.2	9.7	+0.2
30	127.5	28.9	16.3	+0.3
31	123.8	33.7	6.1	-0.2
32	115.8	26.0	1.6	+0.2
33	127.1	30.7	20.0	-0.5

Table 5.15: Leachate Level Changes in the 30-acre wells 30 days After the Drying Procedure.

Well #	Top of PVC Elevation (msl)	Top of PVC to Leachate (ft)	Leachate Depth in Well (ft)	Overall Change of Leachate (ft)
7	105.3	32.9	9.0	-0.5
8	105.2	20.6	19.6	+2.6
17	115.5	38.8	1.1	-1.5
20	113.2	24.8	12.8	-0.6
21	119.5	28.5	11.9	-0.8
22	123.5	30.6	8.9	-0.6
30	127.5	28.9	16.3	+0.3
31	123.8	35.7	4.5	-1.8
32	115.8	27.4	0.2	-1.2
33	127.1	30.2	20.5	0.0

Table 5.16: Leachate Level Changes in the 30-acre wells 60 days After the Drying Procedure.

Well #	Top of PVC Elevation (msl)	Top of PVC to Leachate (ft)	Leachate Depth in Well (ft)	Decrease of Leachate (ft)
5	108.6	42.8	0	0
6	104.4	44.2	0.1	0
7	105.3	32.9	9.1	0.4
8	105.2	23.4	16.8	0.5
9	114.3	34	0.1	0
16	117.9	42.4	0.4	0
17	115.5	38.8	1.1	1.5
18	109.8	39	2.6	0.6
19	112.9	44.1	0.2	0.3
20	113.2	24.8	12.8	0.6
21	119.5	28.5	12	0.7
22	123.5	30.6	8.9	0.6
23	124.7	38.4	0.1	0
29	126.4	41.8	0.4	0
30	127.5	29.2	16	0
31	123.8	35.7	4.1	2.2
32	115.8	27.4	0.2	1.2
33	127.1	30.2	20.5	0
34	132.1	68.4	0	0
35	114.3	42.1	0.1	0
37	134.5	32	0	0
38	138.8	27	0	0

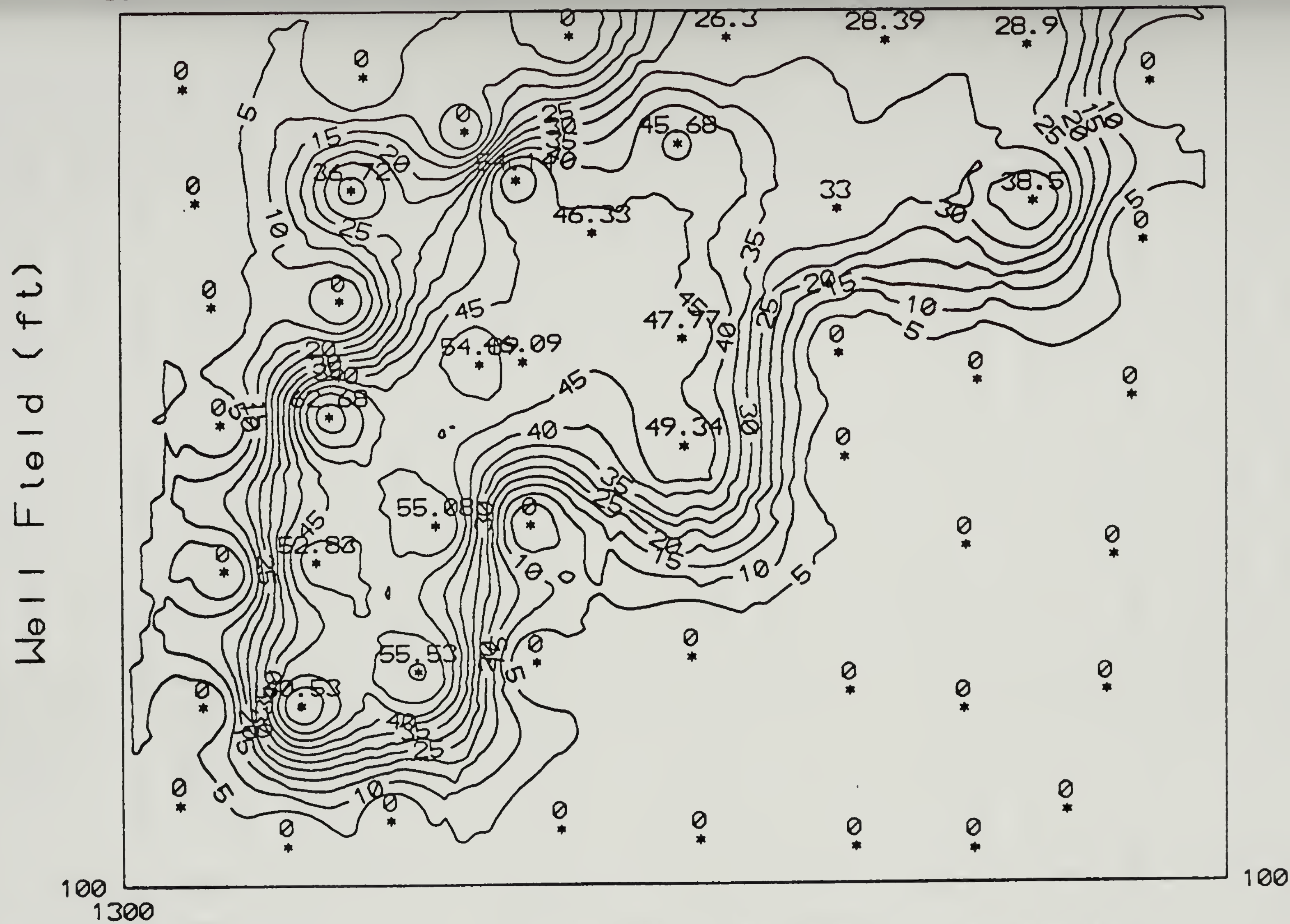

Figure 5-10: Isobaric Plot of the Leachate Levels in the 30 and 11-Acre Wells After Drying (Feet above Groundwater).

depicts the final estimated leachate levels in the well field. The estimated volume removed was 33,000 ft^3. This equates to a removal rate of 8,228 gal/day.

Based on the results, it appears that the assumptions used for determining the input parameters to SURFER were incorrect. The removal rate exceeds the rate which is predicted by the Ideal Gas Law. At this pumping rate, it is estimated that the removal rate should be around 900 gal/day.

Data that was collected on the hours that the gas collection condensate sump pumps operated. During the course of this phase, the pump meters were reset without any prior notification. Therefore, the exact duration of operation was unknown.

The next step was to examine the effect that the assumptions made in running SURFER. Litte is known about the extent of the leachate between the wells. The assumption that all the MSW was completely saturated and that the leachate is hydraulically connected appear to be sources for great error. The volume of leachate removed was calculated based on a zone of saturation 40 feet in the radial direction from the wells and an assumption that the void space was only 50 percent saturated. Based on these assumptions and an average 0.5 foot drop in the 10 wells, the quantity removed is found to be 28,600 gallons or 940 gpd. This relates more closely to what was anticipated.

The drying operations were run for another 7 day period with the flow rate set at 500 scfm. Table 5.17 depicts the leachate levels found before and after and the net change. Based on an average drop of 0.3 feet in the wells and the above assumptions, the leachate removal rate was 2,400 gpd.

Phase V

The last phase of this project was to determine the average biological decomposition rate for the biodegradable portion of the waste. From these conclusions, the quantity of gas anticipated to be available for use in any future waste-to-energy conversion processes can be provided to the County. Previous research by Manley (1992) used data from passive venting as input into the Scholl Canyon Landfill Gas Kinetic model. In summary, this is a model of substrate-limited microbial growth described by the first-order decay equation and is analogous to the biochemical oxygen demand (BOD) tests done on sewage effluent (Schumacher, 1983). The rate of gas production for the entire landfill is determined by summing the gas production of all the individual unit masses of waste. The equation used is as follows:

$$L = \sum_{i=1}^{n} r_i L_{o_i} e^{-k_i t_i}$$

where:

- L equals the methane production rate (scfm).
- Lo equals the ultimate methane production. This value was estimated to be between 2.1 and 3.0 cubic feet of CH_4 per pound of refuse (Schumacher, 1983).
- n equals the number of submasses.
- t equals the time from the placement of the sub-mass to the point at which the composite rate is desired.
- r equals the fraction of the total mass contained in sub-mass i. Data for n, r, and t were provided by CH2M-Hill and are highlighted in Table 5.18.
- k equals the gas production rate constant. This value is based on the estimated half-life of the waste. It is determined by fitting the resulting curve from the model output to the data obtained in Phases I, II and III. Based on passive venting data, Manley (1992) calculated the half-life to be 4.13 years for the 30- and 11-acre areas.

For the purposes of modeling, the value of 3.0 cubic feet of methane per pound of refuse was used as Lo. The output from the model was curve fit to the data points collected in Phases I, II and III by trial and error through adjustment of the decomposition half-life.

Tables 5.19 and 5.20 and Figures 5-11 and 5-12 are model results obtained based on a average decay rate (half-life) of 14.5 years for the 11-acre area and 13.3 years for the 30-acre area. The predicted flow rate for 1993 for a

Table 5.18: Values Used in the Scholl Canyon Model (provided by CH2M-Hill).

	Tons of MSW		
Year	30-acre	11-acre	27-acre
1972	60256		
1973	73944		
1974	79632		
1975	85320		
1976	91008		
1977	96696		
1978	102384		
1979	108072		
1980	113760		
1981	119448		
1982	125136		
1983	130824		
1984	136512		
1985		156370	
1986		126815	
1987		126815	
1988			96173
1989			119987
1990			124322
1991			119600
1992			120000
1993			120000
1994			120000

Table 5.19: Scholl Canyon Model for the 11-acre Area (Lo = 3.0 cf/lb, t(½)= 14.5 years).

year	1985	1986	1987	Yearly avg scfm
1985	422.10			422.10
1986	322.29	342.32		664.60
1987	246.08	261.37	342.32	849.77
1988	187.89	199.57	261.37	648.83
1989	143.46	152.38	199.57	495.41
1990	109.54	116.35	152.38	378.26
1991	83.64	88.83	116.35	288.82
1992	63.86	67.83	88.83	220.52
1993	48.76	51.79	67.83	168.38
1994	37.23	39.54	51.79	128.56
1995	28.43	30.19	39.54	98.16
1996	21.70	23.05	30.19	74.95
1997	16.57	17.60	23.05	57.23
1998	12.65	13.44	17.60	43.70
1999	9.66	10.26	13.44	33.36
2000	7.38	7.84	10.26	25.47
2001	5.63	5.98	7.84	19.45
2002	4.30	4.57	5.98	14.85
2003	3.28	3.49	4.57	11.34
2004	2.51	2.66	3.49	8.66
2005	1.91	2.03	2.66	6.61
2006	1.46	1.55	2.03	5.05
2007	1.12	1.19	1.55	3.85
2008	0.85	0.91	1.19	2.94
2009	0.65	0.69	0.91	2.25
2010	0.50	0.53	0.69	1.72
2011	0.38	0.40	0.53	1.31
2012	0.29	0.31	0.40	1.00

Year	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	Yearly avg scfm
1988	1	3	4	5	8	11	16	22	31	44	62	87	122	418
1989	1	2	3	4	6	8	12	17	23	33	46	65	91	311
1990	1	1	2	3	4	6	9	12	17	25	35	49	68	232
1991	0	1	2	2	3	5	7	9	13	18	26	36	51	173
1992	0	1	1	2	2	3	5	7	10	14	19	27	38	129
1993	0	1	1	1	2	3	4	5	7	10	14	20	28	96
1994	0	0	1	1	1	2	3	4	5	8	11	15	21	72
1995	0	0	0	1	1	1	2	3	4	6	8	11	16	53
1996	0	0	0	1	1	1	1	2	3	4	6	8	12	40
1997	0	0	0	0	1	1	1	2	2	3	4	6	9	30
1998	0	0	0	0	0	1	1	1	2	2	3	5	6	22
1999	0	0	0	0	0	0	1	1	1	2	2	3	5	16
2000	0	0	0	0	0	0	0	1	1	1	2	3	4	12
2001	0	0	0	0	0	0	0	0	1	1	1	2	3	9
2002	0	0	0	0	0	0	0	0	1	1	1	1	2	7
2003	0	0	0	0	0	0	0	0	0	1	1	1	1	5
2004	0	0	0	0	0	0	0	0	0	0	1	1	1	4
2005	0	0	0	0	0	0	0	0	0	0	0	1	1	3
2006	0	0	0	0	0	0	0	0	0	0	0	0	1	2
2007	0	0	0	0	0	0	0	0	0	0	0	0	0	2
2008	0	0	0	0	0	0	0	0	0	0	0	0	0	1

Table 5.20: Scholl Canyon Model, 30-Acre Area (Lo=3.0 cf/lb, t(1/2)=13.3 years.

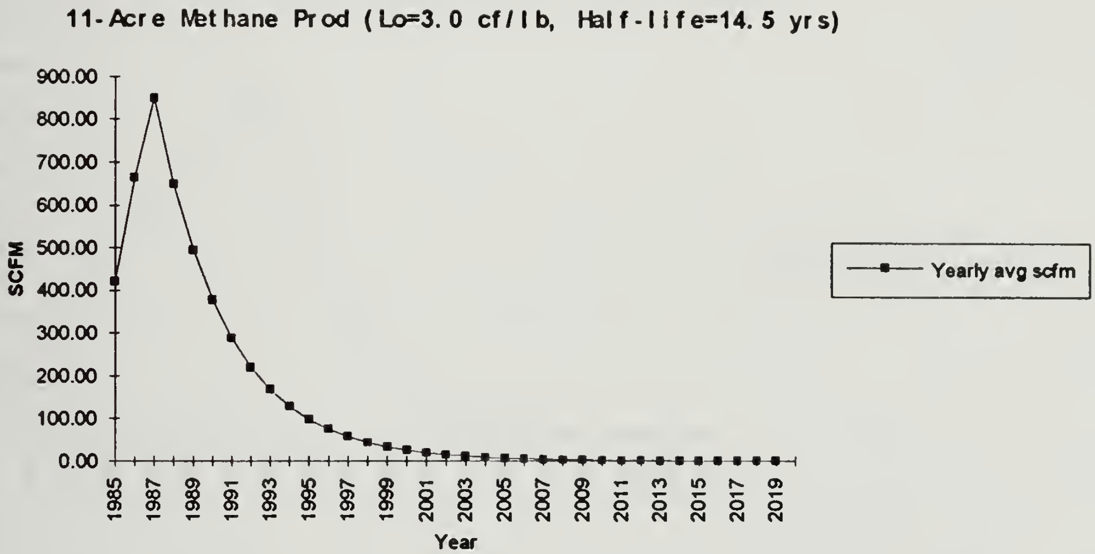

Figure 5-11: Scholl Canyon Model Methane Flow for the 11-Acre Area.

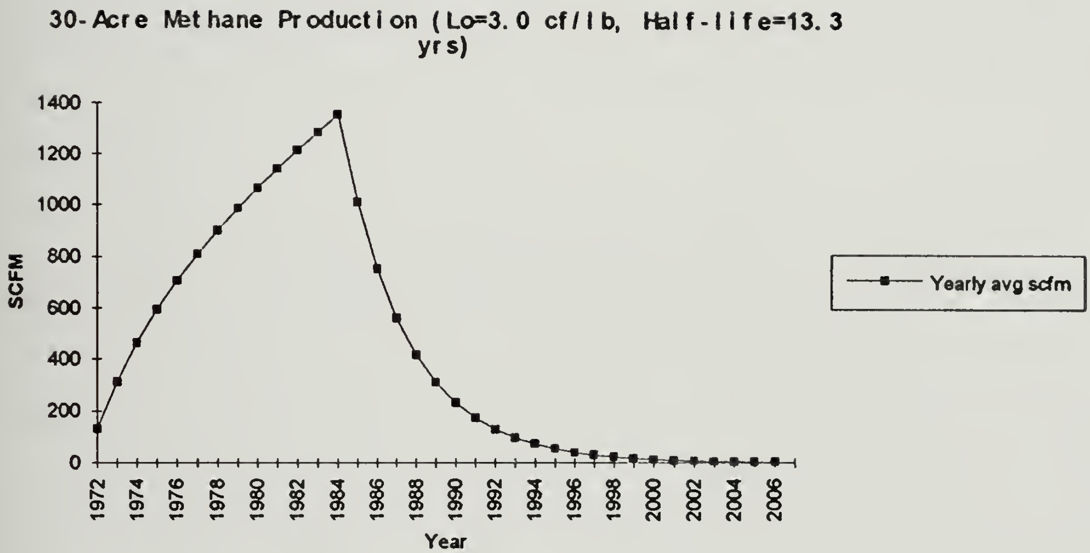

Figure 5-12: Scholl Canyon Model Methane Flow for the 30-Acre Area.

11-acre area was 168 scfm and 96 scfm for the 30-acre area. Comparing these values to the data, a strong agreement is observed.

Based on these values, the Scholl Canyon model calculates that gas production in the 30-acre area has ceased for all portions except the northern-most section. By 2001, the entire 30-acre site will have ceased production (<10 scfm). For the 11-acre and 30-acre areas, the model anticipates that an average of 116 scfm of methane or 117,772 BTU/hr of energy can be collected from this site until 2000 with production ceasing (<10 scfm) in the year 2004.

The data for the active cell had to be carefully reviewed. The wet cell technology being examined by others in the active cell should drastically decrease the half-life for the waste in the wetted area. Additionally, a portion of this site (approximately 25 percent) has been set aside as a control area. In the control area, the waste can be typically classified as the same as the waste in the 11- and 30-acre areas. Therefore, this waste is degrading at an approximate half-life rate of 14 years.

The waste in the wetted area is suspected to be degrading rapidly with a half-life of 2 to 3 years. The Scholl Canyon model was run for half-life values varying from 1 to 14 years. Figure 5-13 and Tables 5.21 to 5.27 depict the results obtained.

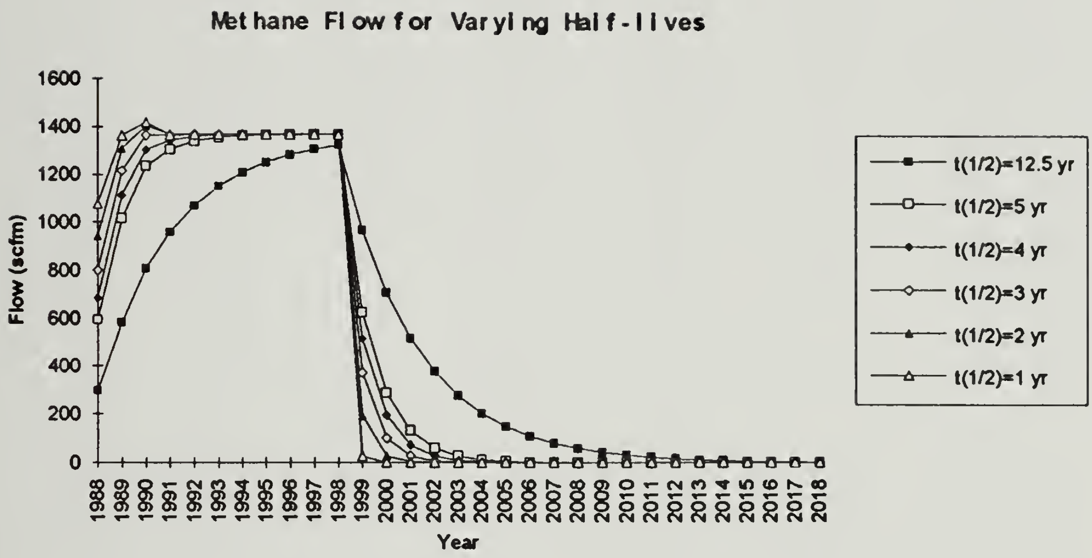

Figure 5-13: Scholl Canyon Model Methane Flow for the 27-Acre with varying Half-lives.

Table 5.21: Scholl Canyon Model for 27-Acre with varying Half-lives.

year	t(1/2)= 12.5 yr	t(1/2)= 5 yr	t(1/2)= 4 yr	t(1/2)= 3 yr	t(1/2)= 2 yr	t(1/2)= 1 yr
1988	295	596	685	800	943	1076
1989	584	1016	1112	1215	1309	1364
1990	808	1235	1304	1364	1404	1418
1991	958	1306	1342	1365	1371	1366
1992	1069	1340	1359	1369	1370	1370
1993	1150	1356	1366	1369	1370	1370
1994	1209	1364	1368	1370	1370	1370
1995	1252	1367	1369	1370	1370	1370
1996	1284	1369	1370	1370	1370	1370
1997	1307	1369	1370	1370	1370	1370
1998	1324	1370	1370	1370	1370	1370
1999	968	626	515	372	194	27
2000	708	286	194	101	27	1
2001	518	131	73	27	4	0
2002	379	60	27	7	1	0
2003	277	27	10	2	0	0
2004	202	13	4	1	0	0
2005	148	6	1	0	0	0
2006	108	3	1	0	0	0
2007	79	1	0	0	0	0
2008	58	1	0	0	0	0
2009	42	0	0	0	0	0
2010	31	0	0	0	0	0
2011	22	0	0	0	0	0
2012	16	0	0	0	0	0
2013	11	0	0	0	0	0
2014	8	0	0	0	0	0
2015	5	0	0	0	0	0
2016	3	0	0	0	0	0
2017	2	0	0	0	0	0
2018	1	0	0	0	0	0

year	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	Yearly avg scfm
1988	295											295
1989	216	368										584
1990	158	269	381									808
1991	115	197	279	367								958
1992	84	144	204	268	368							1069
1993	62	105	149	196	269	368						1150
1994	45	77	109	143	197	269	368					1209
1995	33	56	80	105	144	197	269	368				1252
1996	24	41	58	77	105	144	197	269	368			1284
1997	18	30	43	56	77	105	144	197	269	368		1307
1998	13	22	31	41	56	77	105	144	197	269	368	1324
1999	9	16	23	30	41	56	77	105	144	197	269	968
2000	7	12	17	22	30	41	56	77	105	144	197	708
2001	5	9	12	16	22	30	41	56	77	105	144	518
2002	4	6	9	12	16	22	30	41	56	77	105	379
2003	3	5	7	9	12	16	22	30	41	56	77	277
2004	2	3	5	6	9	12	16	22	30	41	56	202
2005	1	2	3	5	6	9	12	16	22	30	41	148
2006	1	2	3	3	5	6	9	12	16	22	30	108
2007	1	1	2	2	3	5	6	9	12	16	22	79
2008	1	1	1	2	2	3	5	6	9	12	16	58
2009	0	1	1	1	2	2	3	5	6	9	12	42
2010	0	1	1	1	1	2	2	3	5	6	9	31
2011	0	0	1	1	1	1	2	2	3	5	6	22
2012	0	0	0	1	1	1	1	2	2	3	5	16
2013	0	0	0	0	1	1	1	1	2	2	3	11
2014	0	0	0	0	0	1	1	1	1	2	2	8
2015	0	0	0	0	0	0	1	1	1	1	2	5

Table 5.22: Scholl Canyon Model, 27-Acre Section (Lo=3.0 cf/lb, t(1/2)=14 years).

year	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	Yearly avg scfm
1988	596											596
1989	272	743										1016
1990	125	340	770									1235
1991	57	155	352	741								1306
1992	26	71	161	339	743							1340
1993	12	33	74	155	340	743						1356
1994	5	15	34	71	155	340	743					1364
1995	2	7	15	32	71	155	340	743				1367
1996	1	3	7	15	33	71	155	340	743			1369
1997	1	1	3	7	15	33	71	155	340	743		1369
1998	0	1	1	3	7	15	33	71	155	340	743	1370
1999	0	0	1	1	3	7	15	33	71	155	340	626
2000	0	0	0	1	1	3	7	15	33	71	155	286
2001	0	0	0	0	1	1	3	7	15	33	71	131
2002	0	0	0	0	0	1	1	3	7	15	33	60
2003	0	0	0	0	0	0	1	1	3	7	15	27
2004	0	0	0	0	0	0	0	1	1	3	7	13
2005	0	0	0	0	0	0	0	0	1	1	3	6
2006	0	0	0	0	0	0	0	0	0	1	1	3
2007	0	0	0	0	0	0	0	0	0	0	1	1

Table 5.23: Scholl Canyon Model, 27-Acre Section (Lo=3.0 cf/lb, t(1/2)=5 years).

year	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	Yearly avg scfm
1988	685											685
1989	258	855										1112
1990	97	321	885									1304
1991	36	121	333	852								1342
1992	14	45	125	320	855							1359
1993	5	17	47	120	321	855						1366
1994	2	6	18	45	121	321	855					1368
1995	1	2	7	17	45	121	321	855				1369
1996	0	1	3	6	17	45	121	321	855			1370
1997	0	0	1	2	6	17	45	121	321	855		1370
1998	0	0	0	1	2	6	17	45	121	321	855	1370
1999	0	0	0	0	1	2	6	17	45	121	321	515
2000	0	0	0	0	0	1	2	6	17	45	121	194
2001	0	0	0	0	0	0	1	2	6	17	45	73
2002	0	0	0	0	0	0	0	1	2	6	17	27
2003	0	0	0	0	0	0	0	0	1	2	6	10
2004	0	0	0	0	0	0	0	0	0	1	2	4
2005	0	0	0	0	0	0	0	0	0	0	1	1

Table 5.24: Scholl Canyon Model, 27-Acre Section (Lo=3.0 cf/lb, t(1/2)=4 years).

year	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	Yearly avg scfm
1988	800											800
1989	217	998										1215
1990	59	271	1034			*7						1364
1991	16	74	281	995								1365
1992	4	20	76	270	998							1369
1993	1	5	21	73	271	998						1369
1994	0	1	6	20	74	271	998					1370
1995	0	0	2	5	20	74	271	998				1370
1996	0	0	0	1	5	20	74	271	998			1370
1997	0	0	0	0	1	5	20	74	271	998		1370
1998	0	0	0	0	0	1	5	20	74	271	998	1370
1999	0	0	0	0	0	0	1	5	20	74	271	372
2000	0	0	0	0	0	0	0	1	5	20	74	101
2001	0	0	0	0	0	0	0	0	1	5	20	27
2002	0	0	0	0	0	0	0	0	0	1	5	7
2003	0	0	0	0	0	0	0	0	0	0	1	2
2004	0	0	0	0	0	0	0	0	0	0	0	1

Table 5.25: Scholl Canyon Model, 27-Acre Section (Lo=3.0 cf/lb, t(1/2)=3 years).

year	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	Yearly avg scfm
1988	943											943
1989	133	1176										1309
1990	19	166	1218									1404
1991	3	24	172	1172								1371
1992	0	3	24	166	1176							1370
1993	0	0	3	23	166	1176						1370
1994	0	0	0	3	24	166	1176					1370
1995	0	0	0	0	3	24	166	1176				1370
1996	0	0	0	0	0	3	24	166	1176			1370
1997	0	0	0	0	0	0	3	24	166	1176		1370
1998	0	0	0	0	0	0	0	3	24	166	1176	1370
1999	0	0	0	0	0	0	0	0	3	24	166	194
2000	0	0	0	0	0	0	0	0	0	3	24	27
2001	0	0	0	0	0	0	0	0	0	0	3	4
2002	0	0	0	0	0	0	0	0	0	0	0	1

Table 5.26: Scholl Canyon Model, 27-Acre Section (Lo=3.0 cf/lb, t(1/2)=2 years).

year	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	Yearly avg scfm
1988	1076											1076
1989	22	1342										1364
1990	0	27	1391									1418
1991	0	1	28	1338								1366
1992	0	0	1	27	1342							1370
1993	0	0	0	1	27	1342						1370
1994	0	0	0	0	1	27	1342					1370
1995	0	0	0	0	0	1	27	1342				1370
1996	0	0	0	0	0	0	1	27	1342			1370
1997	0	0	0	0	0	0	0	1	27	1342		1370
1998	0	0	0	0	0	0	0	0	1	27	1342	1370
1999	0	0	0	0	0	0	0	0	0	1	27	27
2000	0	0	0	0	0	0	0	0	0	0	1	1

Table 5.27: Scholl Canyon Model, 27-Acre Section (Lo=3.0 cf/lb, t(1/2)=1 year).

By assuming that the wetted section has a half-life of 2 years and accounts for 75 percent of the active cell fill and a 14 year half-life for the remaining fill, an overall half-life value of 5 years was calculated using a weighted average. Based on this half-life value, the total quantity of gas production predicted for the active cell was determined to be 1356 scfm methane. Table 5.12 accounts for 742 scfm of methane from the surface, face and clean-out line. An average 5 year half-life for the waste in the active cell translate to 614 scfm of metane that can be collected from the HIL system.

By using a half-life of five years for the active cell and the above half-lives for the 11- and 30-acre areas, the estimated flow to the blowers from all three areas as configured now (without HIL) and as predicted by the Scholl Canyon model will be 400 cfm of methane or 404,800 BTU/hr over the next six years. If the landfill closes as scheduled in 1998, the model predicts that gas production at the ACSWLF will cease (<10 scfm) by the year 2005 (See Figure 5-14 and Table 5.28).

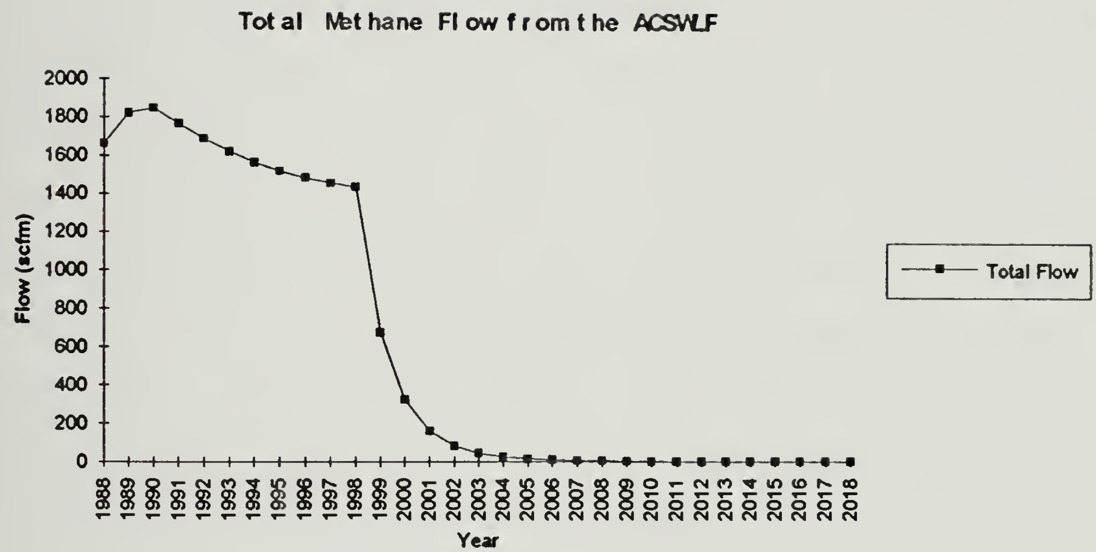

Figure 5-14: Total Methane Flow from the ACSWLF.

CHAPTER 6
CONCLUSIONS

In 1991, a decision was made to install a gas collection system at the ACSWLF to prevent gas migration and odor problems emanating from the 11- and 30-acre landfills. The design team developed a system that they felt would meet the County's needs. It does! Unfortunately once the system was installed, the County began to examine possible ways to utilize the gas being collected. One of the objectives of this study was to determine the average biological decay rates for the bidegradable portion of the deposited waste (half-life). From these values, a determination as to how much gas can be collected and the expected gas recovery rates over the next ten years was made.

The Scholl Canyon Landfill Gas Kinetic Model was used in the the prediction of the half-life. Results of the data collected reveal that the County can expect no further quantities of gas from the wells on the southern five collection laterals in the 30-acre area. The connection of these wells to the blowers will only lead to the introduction of air into the system and therefore lower the quality of the gas available for conversion. The model predicted that the half-life for this area of waste to be 13.3 years.

For the 11-acre area, the data support the conclusion that this area is still producing gas at a rate of 350 scfm at an approximate quality of 48 percent methane or 166 scfm of methane. The Scholl Canyon model estimates the half-life to be 14.5 years for this area. If no contamination of the anaerobic environment occurs, the results of the model predict that the quantity of gas emitted from the 11- and 30-acre areas will average 116 scfm of methane until the year 2000.

With the installation of the Accu-Flo wellheads and the purchase of the Landtec Gas Analyzer, the gas quality and quantity being collected from the individual wells in the 11-acre area can be easily monitored. Monthly monitoring will ensure that those areas that are producing less gas than others are adjusted to prevent the introduction of air.

In this study, an attempt was also made to quantify the volume of gas produced in the 27-acre active area. While providing the least amount of disruption to the daily landfilling operations, connections were made to the leachate collection system clean-out line. Initially, only small amounts of the gas generated in the 27-acre area were collected. After installation of a larger connection to the clean-out line, initial results reveal that the quantity of gas collected dramatically increased from 63 scfm to 535 scfm. It appears that this setup is a viable use of a leachate collection system to collect gas from an active

cell. But because of the numerous delays that were encountered in the installation of this system, very little data was collected under this study. Further study of the quantity and quality of gas being collected via this method are required before any recommendations can be made on the installation of this system in other landfills.

In order to further quantify the volume of gas escaping from the uncapped active cell, a review and extrapolation of the literature was conducted. Reinhart (1993) concluded that the surface emission rate for the ACSWLF active cell was 0.00035 scfm/sf. Based on this data and an estimated surface area of over 18 acres, it was determined that 742 scfm of methane was escaping from the surface and northern face of the 27-acre area.

Combining the above data, estimating the quantity escaping from the HIL system, and accounting for the Wet Cell technology in this area, the Scholl Canyon model predicts that the half-life for the active cell is 5 years. Because of the waste was wet in this area, the half-life decrease by over 180 percent.

The final area examined in this study was the use of a gas collection system to dry out degraded waste. By pulling high quantities of gas from portions of the landfill where leachate has accumulated, moisture can be removed from the waste. The technique used in this study to determine the pre-existing volume and the estimated quantity removed is

not valid. The assumptions that had to be made to run the SURFER program introduced excessive error in the estimated quantities. The model used estimated that 33,000 ft^3 of leachate was removed over a 30 day period. This equates to 8,228 gal/day. The Ideal Gas Law only predicts that 900 gal/day can be expected under best case conditions. It is concluded that leachate was removed, but the quantity has not been determined. It is recommended that future efforts employ a more accurate means of measuring the volume of leachate removed, such as installing a flow meter and a data logger on the condensate sump pumps.

APPENDIX A

CONDENSATE CALCULATIONS

Tchobanoglous et al., 1993.

Determine the amount of condensed water vapor that must be removed daily from a landfill gas recovery system based on the following data and assumptions:

1. Total gas flow = 1000 scfm (60°F, 14.7lb/in^2)
2. Temperature of landfill gas as it exits the landfill = 130°F
3. Temperature of landfill gas at the blower station = 90°F
4. Vacuum at well head = 36 in H_2O
5. Vacuum at blower = 47 in H_2O
6. Landfill gas is saturated in water vapor at the well head

Solution:
1. Determine the total pounds of water present in the water vapor in the saturated landfill gas at the well head.

(a) Determine the volume of gas at the well head relative to the volume at standard conditions (60°F, 14.7 lb/in^2).

$$\left(\frac{PV}{T}\right)_1 = \left(\frac{PV}{T}\right)_2$$

P_1 = 14.7 lb/in^2 = 33.9 ft H_2O
V_1 = 1000 cfm
T_1 = 460 + 60 = 520°R
P_2 = 33.9 ft H_2O - 3 ft H2O = 30.9 ft H_2O
V_2 = ? cfm
T_2 = 460 + 130 = 590°R

$$V2 = 1000cfm\left(\frac{590}{520}\right)\left(\frac{33.9}{30.9}\right) = 1245cfm$$

b) Determine the moles of water vapor present in the LFG at the wellhead using the Ideal Gas Law:

$$p_v V = nRT$$

Pv = vapor pressure of H_2O at 130°F = 319.7 lb/ft^2
R = 1543 ft-lb/(lb-mole)-°R
T = 590°R

$$n = \frac{p_v V}{RT} = 0.4366 lb - mole / \min$$

c) lb H2O = 0.4366 lb-mole/min * 18 lb/lb-mole = 0.95 gal min
2) Determine the pounds of water as water vapor at the blower:
a) Determine the volume of LFG at the blower:

P_1 = 14.7 lb/in^2 = 30.9 ft H_2O
V_1 = 1245 cfm
T_1 = 460 + 130 = 590°R
P_2 = 33.9 ft H_2O - 3.9 ft H_2O = 30.0 ft H_2O
V_2 = ? cfm
T_2 = 460 + 90 = 550°R

$$V_2 = 1245cfm\left(\frac{550}{520}\right)\left(\frac{33.9}{30.0}\right) = 1195cfm$$

b) Determine the moles of water vapor in the LFG at the blower:

$$p_v V = nRT$$

Pv = vapor pressure of H_2O at 90°F = 100.8 lb/ft^2
R = 1543 ft-lb/(lb-mole)-°R
T = 550°R

$$n = \frac{p_v V}{RT} = 0.142 lb - mole / \min$$

c) Determine the pounds of water vapor present at the blowers:

lb H_2O = 0.142 lb-mole/min * 18 lb/lb-mole = 0.31 gal/min

3) Determine the amount of vapor condensed daily:

lb H2O at Wellhead - lb H2O at Blower = 0.95 -0.31 gpm

0.64 gpm = **<u>900 gpd</u>**.

APPENDIX B

FLARE OPERATION PROCEDURES

UTILITY FLARE STATION
START-UP

To assure both personal and equipment safety, a qualified LFG Specialties factory representative should be present for the initial start-up and commissioning of the utility flare system.

The factory representative will check the following prior to attempting any flare start-up:

A. Proper Installation - the equipment has been properly installed and all external piping and wiring connections are complete and correct.

B. System Checkouts - all the piping, wiring and equipment is correctly assembled and no items have been removed or damaged in transport and/or installation.

C. Flame-Trol I - the flare control system is in proper running order and the preprogrammed settings in the controller are per factory specification.

D. Valving - all automated and manual valves are correctly installed and operative.

E. Blower - the blower is bumped to check rotation and verify the wiring is correctly installed.

F. Pilot - there is a sufficient supply of pilot gas at the correct pressure.

G. Extraction System - verify with customer/contractor that the gas extraction system is complete, all the control valves are in correct position, and the system is ready to operate and supply landfill gas to the flare station.

After all the preceding is checked and verified, the utility flare system is ready for initial start-up.

INITIAL MANUAL START-UP

1) Verify that the pre-start checklist has been satisfactorily completed.

2) Turn on the main power to the system and the individual equipment circuit breakers.

3) Turn on Flame-Trol I controller power switch.

4) Place controller mode operation switch to "manual".

5) Turn the manual pilot fuel supply switch to the on position.

6) Depress the manual ignitor button and hold until the pilot gas is ignited and burning. This can be verified by a rising temperature on the LED temperature readout.

7) Turn on the main header valve switch which will open the header valve and allow the landfill gas to the flare.

8) Turn on the blower switch which will start the blower.

9) The landfill gas will be ignited. The flame can be confirmed either by visual confirmation or by a rising temperature on the LED temperature readout.

10) Once all the air is purged from the header system and a stable flame is established, turn off the pilot fuel switch.

11) The utility flare system is now operating in manual mode.

12) The flare can be shut-down by turning off the power switch or pushing the emergency stop button.

13) The flare is equipped with a manual timer. This timer is activated once the system is switched to the manual mode. If the system was left running for an extended period of time in the manual mode, the timer will eventually shut the system down.

Note: **The flare system should not be left operating unattended in manual mode as all system permissive and safety shutdowns are bypassed.**

INITIAL AUTOMATIC START-UP

1) The utility flare system should be started in manual mode to verify gas flows and mechanical systems prior to the initial automatic start-up.

2) Check temperature controller settings. The Flame-Trol I uses two settings on the temperature controller. These are:

   Set Point or Set Value - (lower setting of the temperature controller). This temperature setting will induce the following:

   a - During start-up
     - Opens the main gas header valve.
     - Starts the blower.

   b - During shut-down (back-up to ultraviolet sensor)
     - Stops the blower.
     - Closes the gas header valve.

   High Alarm - (higher setting of the temperature controller). This temperature setting will induce the following:

   a - During start-up
     - Shuts the solenoid valve for the propane line (shutting off the pilot).
     - Activates the ultraviolet scanner.

   b - During shut-down
     - Activates the down timer.

These temperatures are set in the controller at the factory. If site operating conditions dictate changes in the settings, refer to the Fuji Micro Controller E Instruction Manual in the Flame-Trol I section of this manual for detailed procedures.

In making modifications or adjustments to the temperature settings note the following:

A. Turn the blower selector switch to the "off" position when making temperature settings.

B. The Set Value (SV) is the temperature that allows the controller to verify that the pilot is ignited prior to starting the blower . The pilot system is designed to reach a maximum temperature reading of 500 degrees fahrenheit. Therefore, to conserve the pilot gas, this setting should be considerably lower than 500 degrees. On the other hand, the set value temperature is also the temperature that shuts down the flare system and a certain margin should be considered between that temperature and the atmospheric temperature.

C. High Alarm setting is the temperature that allows the controller to determine that the landfill gas is ignited and to shut off the pilot gas supply. This temperature should be higher than the (SV) temperature.

For more information on the temperature controller, refer to the Fuji PYZ-4 Micro Controller Manual in the Flame-Trol I section of this manual.

3) Check the setting on the down time timer.

The function of the down time timer is to allow the operator to regulate the length of time the system will remain shut down before attempting automatic restart.

The timer is preset at the factory and is in the minute range as indicated by the "M" on the time range selector. This gives the timer a range of 1 to 999 minutes. To change the setting in the down timer, simply increase or decrease the number desired by pressing the + button above the number to increase or by pressing the - button below the number to decrease.

This timer will begin timing down only after the temperature controller has fallen below the set point temperature.

For more information on the down time timer, refer to the Omron H3CA operation manual in the Flame-Trol I section of this manual.

4) Check the setting on the pilot timer.

The purpose of the pilot timer is to specify a set period of time to allow the pilot system to attain the blower-on temperature set in the temperature controller. For instance, if the pilot timer has been set at five minutes and the blower-on temperature (SV) is set at 300 degrees, the pilot will have five minutes to heat the thermocouple to 300 degrees. If the pilot system fails, due to an exhausted pilot gas supply or other reasons, to attain the blower-on temperature in the time period allotted, the entire system will shut-down and the pilot failure light will come on. The system will not go into the down time mode and therefore will not try to reignite until the pilot problem has been rectified.

The pilot timer is preset at the factory and is in the minute range as indicated by the "M" on the time range selector. This gives the timer a range of 1 to 999 minutes. To change the setting in the pilot timer, simply increase or decrease the number desired by pressing the + button above the number to increase or by pressing the - button below the number to decrease.

The letter to the left of the setting digits on the pilot timer is the operation mode setting. The mode setting will generally be set on "E" indicating interval operation. The only exception to this would be in the event the operator wished to maintain the pilot flame, in which case the operation mode should be set by "D" indicating signal off. This in effect bypasses the pilot timer to leave the pilot flame burning for an indefinite period of the time, providing the landfill flame has not raised the temperature of the thermocouple system to the pilot-off set point.

For more information on the pilot timer, see the Omron H3CA operating manual in the Flame-Trol I section of this manual.

5) Check the setting on the ignitor timer

Below the front cover plate in the controller is another timer identical to the pilot timer which times the ignitor spark to the pilot. This timer has been set at the factory at three minutes which allows a constant sparking action by the ignitor for this period of time. This should be adequate time to purge the pilot gas line of air and ignite the pilot. This timer should never have to be altered. But in the event the operator does wish to change the setting, this may be accomplished in the same manner as the pilot timer.

6) Turn the blower switch/s to the desired blower/s. In single blower applications, the switch may be omitted.

7) Turn the master switch to "Auto". The Flame-Trol I will now run through the automatic start-up sequence and ignite the flare.

8) The portable flare station will continue to operate in the automatic mode until shut-down.

Once the initial automatic start-up is completed and all site condition operating adjustments have been made, the flare station is considered commissioned and fully operative. For operation of the package beyond this point refer to the standard operating procedure in this section of the manual.

OPERATION

The LFG Specialties utility flare system is designed for fully automatic, unattended operation. To familiarize yourself with the features and flexibility of the complete system, please review this operation and maintenance manual prior to proceeding with the start-up or adjustment of the control system.

To assure both personal and equipment safety, a qualified LFG Specialties factory representative should have completed the initial start-up and commissioning of the utility flare station before standard operation is commenced. The qualified representative will also conduct an on-site training session with the customer's operating personnel to assure safe and efficient operation of the utility flare station.

Under standard operating conditions, all that is required to start the utility flare is to turn the operation mode switch in the Flame-Trol I controller to "Auto". The controller will then automatically start the system proceeding through the following logic sequence:

1) Placing the operation mode switch in "Auto", will activate the pilot gas solenoid valve and pilot ignitor timer.
   Permissive: Flare stack temperature reading must be below the set point in the temperature controller.
   The ultraviolet scanner must be locked out.

2) The pilot will ignite and raise the thermocouple temperature to the blower-on set point.

3) At the blower-on set point the controller will start the blower and activate the automatic landfill gas header valve.
   Permissive: The pilot must achieve the set point temperature within the time set in the pilot timer or the system will be shut-down indicating "pilot failure".

4) The pilot will ignite the landfill gas and raise the thermocouple temperature to the pilot-off set point, which is the High Alarm setting.

5) At the pilot-off set point, the controller will shut off the pilot gas solenoid valve and activate the ultraviolet scanner.

6) The flare will continue to operate until the supply of combustible landfill gas is interrupted to the point that the flame extinguishes.

7) The ultraviolet scanner will sense the flame out and automatically shut-down the system within four seconds. The scanner signals the blower to stop and activates the closure of the main header valve.

   Backup: Should the ultraviolet scanner fail to function for any reason, it is backed up by the temperature controller. If the flame extinguishes, the temperature reading will fall below the set point and also signal a system shut-down.

8) As the temperature falls below the high alarm setting, the controller will activate the down timer.

9) The down timer will run through its time setting and then restart the system by activating the automatic start switch. The sequence will repeat itself from step one.

10) The controller will continue to operate, monitor and restart the system as long as the pilot failure is not indicated. Should a pilot failure occur, due to lack of pilot gas or any other reason, the problem will have to be corrected and the system is reset by pushing the reset button.

Along with the operating switch and LED readouts indicated, the Flame-Trol I also has ten function lights, including:

"POWER ON" - This light is on whenever the master switch is turned on and the panel is powered.

"AUTOMATIC" - This light indicates that the operation mode selector switch is in the automatic position.

"PILOT ON and IGNITOR ON" - These lights will only be on during the pilot and ignitor functions. Note: Pilot function is from the time the pilot fuel valve opens until the temperature reaches the pilot off setting in the temperature controller.

"HEADER OPEN" - This light indicates that the landfill gas header valve is in the fully open position.

"BLOWER ON" - This light indicates that a flame is burning and the blower is running.

"FLARE SHUTDOWN" - The Flare Shutdown light will go on whenever the flare is down for any reason while the controller is in the automatic mode.

"PILOT FAILURE" - This light will come on if the temperature does not reach the blower on temperature in the length of time set in the pilot timer. When a pilot failure occurs, the system will shut down and will not go to down time or try to reignite automatically. The pilot problem must be remedied and the pilot failure manually reset to reinstate the automatic controls.

"FLAME OUT" - If the flame goes out for any reason during normal flare operation the ultraviolet scanner will initiate the system shutdown and the Flame Out light will go on.

"ARRESTOR HIGH TEMP" - The flare system is equipped with a temperature switch that monitors the landfill gas temperature at the flare inlet. If an above normal temperature is detected (> 235 °F), the switch will shutdown the system and the Arrestor High Temperature light will go on.

for any reason manual operation of the system is desired, the ame-Trol I controller has the following functions:

"Off-Manual-Auto Switch" - This switch allows the operator to temporarily operate the system manually (in the manual position) or completely shut-down the system (in the off position). Note: The blowers will not run under any circumstance with the controller in the off position.

"Manual Ignitor button and Pilot fuel switch" - The pilot may be ignited by switching the manual pilot fuel switch to the on position and depressing the manual ignitor button in the controller. Keep button depressed for a period long enough to allow air to be purged from the pilot gas supply line. The manual ignitor button will only function with the off-manual-auto-switch in the manual position.

"Blower and Header Switches" - These switches allow the operator to start the blower and activate the main header valve in the manual mode.

NOTE: As the manual mode will bypass all the system permissive and safety shut-downs, Flame Trol I is provided with a safety timer to limit the maximum time the system is allowed to run in the manual mode.

APPENDIX C

GAS SAMPLING PROCEDURES

Gas Chromatograph Gas Sampling Procedure

A. Reference:

1. Instruction manual for Gas Chromatograph/Thermal Conductivity Detector.

B. Discussion:

1. This protocol is based upon reference #1. The operator should review this manual prior to conducting this analysis.

2. All sample bottles must be flushed with clean air prior to commencement of analysis.

3. Upon completion of this analysis, the operator should clean all materials and restore all equipment to its original condition and location.

C. Equipment and Materials:

1. 250 ml polypropylene sample bottles w/ septum (Fisher Cat No 10-922-5).

2. Gas Chromatograph w/Thermal Conductivity Detector (Bio-Process Lab).

3. 60 ml sampling syringe (Bio -Process Lab).

4. Calibration Gas (Methane, Nitrogen, Oxygen, Carbon Dioxide)

5. Sample bottle adapter w/ Tygon tube to connect sampling port. (Rm 321)

6. 2" PVC or 3/8" brass pronged sample port adapter (room 321).

7. 3/8" open ended wrench (room 321).

8. Cloth rags (room 321).

9. Transportation container (room 321).

10. Field notebook.

D. Analysis:

STEP 1: Collection of Sample (Flare Station):

1. Remove 3/8" plug from flare station sample port located beneath the output pressure gauge.

2. Install 3/8" brass pronged adapter into opening.

3. Connect the 1/8" Tygon tubing to the adapter and to the sample bottle.

4. Open stop cock and remove screwed-on septum on 250 ml bottle and allow gas to flow through for approximately 2 minutes.

5. Replace the septum, then close the stop cock.

6. Note the bottle identification and well sampled into field notebook.

7. Place bottle into transportation container.

8. Repeat steps 3-7 at the same sample port (duplicate sample).

9. Transport to Bio-Process Lab for analysis

STEP 2: Gas Chromatograph Analysis (Calibrate):

1. Turn on carrier gas to GC (valve is located behind the GC on the left side).

2. Place column indicator switch to columns 1 & 2 mode and Attenuation dial to 4.

3. Ensure adequate flow of carrier gas by squeezing soap indicator bubble on the left hand side of the machine and observe the soap bubbles that were formed rise.

4. Only after carrier gas is confirmed to be flowing, turn on the Bridge Power.

5. Allow Gas Chromatograph unit to warm up.

6. Press "Level" periodically and observe the change in values. Once this value has stabilized (Approx 15-20 min), then proceed.

7. Press "Use File", "5", "Enter" on printer. Note: Printer should always remain on.

8. Press "Calib", "1", "Enter".

9. Open the calibration gas cylinder at top of bottle.

10. Insert needle from the 60 ml syringe into the calibration gas septum.

11. Open the Regulator valve and draw a 40 ml sample.

12. Insert needle into the injection port septum on the left side of the GC.

13. Pull the injection loop valve open and inject sample.

14. Push the injection valve closed.

15. Immediately press "inject" button on printer.

16. The GC sets this run as the standard for analysis. Verify that the standard is correct by repeating Steps 9-14.

17. Observe how well the standard predicted the known concentration of the calibration gas. If the concentrations

determined are not w/in 1% of the actual known concentrations, then repeat Steps 8-17 until results are satisfactory (usually 2-3 times are necessary).

STEP 3: Gas Chromatograph Analysis (Landfill Gas):

1. After proper calibration, insert needle into the sample bottle septum and draw a 40 ml sample.

2. Perform Steps 12-15 two times for each sample bottle.

3. Remove printed data from printer.

4. Turn off Bridge power first.

5. Turn off carrier gas. Note: the printer remains on.

6. Close valve on the calibration gas bottle.

specifies double spacing. You might need other formats provided by the style sheet.

<u>Landtec Gas Analyzer Sampling Procedure</u>

A. References:

Landtec, GEM-500 Gas Extraction Monitor Operation and Maintenance Manual, ver 1.41, Feb 1993

B. Discussion:

1. The gas analysis protocol is based upon the procedures outlined in the O&M manual for the use of the Landtec GEM-500 Gas Extraction Monitor.

2. The monitor should be field calibrated before each round of sampling.

3. The flare system needs to be operating for system optimization.

4. The monitor should be properly charged.

5. The date/time setting should be checked.

6. Perform Zero Pressure check.

7. Check gas alarm settings.

C. Equipment and Materials:

1. Landtec GEM-500 Gas meter.

2. Landtec calibration gas cylinders. Note: Both of these items are owned and maintained by the ACSWLF.

D. Analysis:

The following is a listing of the steps required in the analysis of the landfill gas. All page references are those found in the O&M manual.

1. Check battery charge. p57

2. Field Calibrate meter. P8-21

3. Check Date/Time p27

4. Perform Zero Pressure p28-29

5. Check gas alarm settings p32-33

6. Read gas levels p37-41

7. Read gas pressure and temperature p 41-43

8. Logging gas data p43-45

9. Print/View gas data p45-48

10. Down load data to PC p49-51

E. Quality Control Measures:

1. Specifications and Measurement Units p59

2. Specifications and Accuracy p60.

APPENDIX D

WELLFIELD PRESSURE DATA

Date: 08 Mar 93
Wellfield configuration: All wells open.
Blower Flow: 6.6 inches of water (vacuum).
Blower Vacuum: 500 scfm.

Gas Vent	Valve Status	Pressure ("H2O vac)	Gas Vent	Valve Status	Press ("H2O vac)
1	open	1.0	29	open	1.2
2	open	0.8	30	open	2.0
3	open	0.8	31	open	1.2
4	open	0.5	32	open	1.3
5	open	0.6	33	open	1.8
6	open	0.6	34	open	1.2
7	open	1.0	35	open	1.0
8	open	1.0	36	open	1.8
9	open	0.4	37	open	1.6
10	open	1.0	38	open	1.6
11	open	1.0	39	open	1.6
12	open	1.2	40	open	1.8
13	open	1.4	41	open	1.2
14	open	1.1	42	open	0.6
15	open	1.0	43	open	1.4
16	open	1.0	44	open	1.4
17	open	1.0	45	open	2.0
18	open	0	46	open	2.0
19	open	1.0	47	open	1.0
20	open	1.6	48	open	2.0
21	open	1.4	49	open	1.8
22	open	1.3	50	open	1.0
23	open	1.8	51	open	1.6
24	open	1.6	52	open	1.0
25	open	2.0	53	open	1.4
26	open	1.2	54	open	1.4
27	open	1.8	56	open	1.4
28	open	1.2			

Date: 09 Mar 93
Wellfield configuration: Wells #1-25, 27, 29, 31, 32 and 35 closed.
Blower Flow: 8.3 inches of water (vacuum).
Blower Vacuum: 456 scfm.

Gas Vent	Valve Status	Pressure ("H2O vac)		Gas Vent	Valve Status	Press ("H2O vac)
1	closed			29	closed	
2	closed			30	open	6.3
3	closed			31	closed	
4	closed			32	closed	
5	closed			33	open	6.4
6	closed			34	open	5.2
7	closed			35	closed	
8	closed			36	open	6.5
9	closed			37	open	6.6
10	closed			38	open	6.9
11	closed			39	open	6.8
12	closed			40	open	6.9
13	closed			41	open	
14	closed			42	open	4.0
15	closed			43	open	7.7
16	closed			44	open	7.5
17	closed			45	open	7.2
18	closed			46	open	7.4
19	closed			47	open	5.3
20	closed			48	open	7.2
21	closed			49	open	7.2
22	closed			50	open	6.0
23	closed			51	open	7.0
24	closed			52	open	6.2
25	closed			53	open	6.8
26	open	6.0		54	open	6.8
27	closed			56	open	7.1
28	open	6.3				

Date: 11 Mar 93
Wellfield configuration: Wells #1-25, 27, 29, 31, 32 and 35 closed.
Blower Flow: 11.4 inches of water (vacuum).
Blower Vacuum: 496 scfm.

Gas Vent	Valve Status	Pressure ("H2O)	Gas Vent	Valve Status	Press ("H2O)
1	closed		29	closed	-0.4
2	closed		30	open	-6.3
3	closed		31	closed	-1.2
4	closed		32	closed	-0.7
5	closed		33	open	-6.4
6	closed		34	open	-5..2
7	closed		35	closed	0
8	closed		36	open	-6.5
9	closed		37	open	
10	closed		38	open	
11	closed		39	open	
12	closed		40	open	
13	closed		41	open	
14	closed		42	open	
15	closed		43	open	
16	closed		44	open	
17	closed		45	open	
18	closed		46	open	
19	closed	+0.2	47	open	
20	closed	+0.2	48	open	
21	closed	+0.1	49	open	
22	closed	0	50	open	
23	closed	+0.1	51	open	
24	closed	+0.2	52	open	
25	closed	-0.1	53	open	
26	open	-0.4	54	open	
27	closed	+0.4	56	open	
28	open	-5.6			

Date: 30 Mar 93
Wellfield configuration: Wells #1-8, 11-14, 17-21, 23-25 and 35 closed.
Blower Flow: 6.5 inches of water (vacuum).
Blower Vacuum: 506 scfm.

Gas Vent	Valve Status	Pressure ("H2O)		Gas Vent	Valve Status	Press ("H2O)
1	closed	0		29	open	
2	closed	0		30	open	
3	closed	0		31	open	
4	closed	0.05		32	open	-4.5
5	closed	0		33	open	
6	closed	0.05		34	open	
7	closed	0		35	closed	+0.1
8	closed	0		36	open	
9	open	-3.5		37	open	
10	open	-3.5		38	open	
11	closed	-0.4		39	open	
12	closed	-0.05		40	open	
13	closed	-0.05		41	open	
14	closed	-0.4		42	open	
15	open	-3.5		43	open	
16	open	-3.7		44	open	
17	closed	-0.4		45	open	
18	closed	0		46	open	
19	closed	+0.15		47	open	
20	closed	+0.1		48	open	
21	closed	-0.1		49	open	
22	open	-3.5		50	open	
23	closed	-0.4		51	open	
24	closed	0		52	open	
25	closed			53	open	
26	open			54	open	
27	closed			56	open	
28	open					

Date: 15 Apr 93
Wellfield configuration: Wells #1-25 and 35 closed.
Blower Flow: 9.3 inches of water (vacuum).
Blower Vacuum: 474 scfm.

Gas Vent	Valve Status	Pressure ("H2O)	Gas Vent	Valve Status	Press ("H2O)
1	closed		29	open	
2	closed	0	30	open	-7.3
3	closed		31	open	
4	closed		32	open	-7.5
5	closed	0	33	open	
6	closed		34	open	
7	closed	+0.5	35	closed	
8	closed		36	open	
9	open		37	open	-7.5
10	open	+0.5	38	open	
11	closed		39	open	-7.5
12	closed	0	40	open	
13	closed		41	open	
14	closed	0	42	open	-4.6
15	open		43	open	-8.3
16	open		44	open	-7.6
17	closed	+0.1	45	open	
18	closed		46	open	
19	closed	+0.1	47	open	
20	closed		48	open	
21	closed		49	open	-7.7
22	open	+0.1	50	open	-6.7
23	closed		51	open	
24	closed	0	52	open	
25	closed	-0.5	53	open	
26	open		54	open	
27	closed	-6.5	56	open	-7.7
28	open				

Date: 01 Jul 93
Wellfield configuration: Wells #7, 8, 17 26-36, 41, 42 and 43 open (drying operations).
Blower Flow: 54.6 inches of water (vacuum).
Blower Vacuum: 750 scfm.

Gas Vent	Valve Status	Pressure ("H2O)		Gas Vent	Valve Status	Press ("H2O)
1	closed	+0.1		29	open	
2	closed			30	open	
3	closed	+0.2		31	open	
4	closed			32	open	-42.0
5	closed			33	open	-38.0
6	closed	+0.2		34	open	
7	open	-32.0		35	closed	
8	open	-42.0		36	open	
9	closed	-1.5		37	closed	+13
10	closed	+0.05		38	closed	+13
11	closed	+0.05		39	closed	+13
12	closed	+0.05		40	closed	+14
13	closed	+0.05		41	open	
14	closed	0		42	open	
15	closed	-0.5		43	open	
16	closed	-1.0		44	closed	+13
17	open	-21.0		45	closed	+14
18	closed			46	closed	+15
19	closed			47	closed	+13
20	closed			48	closed	+14
21	closed			49	closed	+15
22	closed			50	closed	+13
23	closed	-3.0		51	closed	+13
24	closed	-1.5		52	closed	+14
25	closed			53	closed	+13
26	open			54	closed	+13
27	closed			56	closed	+13
28	open					

Date: 13 Aug 93
Wellfield configuration: Wells #7, 8, 17, 20, 21, 22, and 26-56 open (drying operations). Active tie-in connected.
Blower Flow: 41.0 inches of water (vacuum).
Blower Vacuum: 950 scfm.

Gas Vent	Valve Status	Pressure ("H2O)	Gas Vent	Valve Status	Press ("H2O)
1	closed		29	open	-1.5
2	closed		30	open	-29
3	closed		31	open	-6
4	closed		32	open	-34
5	closed		33	open	-16
6	closed		34	open	
7	open		35	closed	-3.5
8	open		36	open	-3
9	closed		37	open	-13
10	closed		38	open	-24
11	closed		39	open	-10
12	closed		40	open	-5
13	closed		41	open	-25
14	closed		42	open	-2.5
15	closed		43	open	-23
16	closed		44	open	-12
17	open		45	open	-12
18	closed		46	open	-38
19	closed		47	open	-7
20	open		48	open	-9
21	open		49	open	-22
22	open		50	open	-0.5
23	closed		51	open	-9
24	closed		52	open	-5
25	closed		53	open	-6
26	open	-15	54	open	-5
27	closed	-4	56	open	-24
28	open	-3			

Date: 30 Sep 93
Wellfield configuration: Wells #1-25 and 35 closed. 11 gate valves installed this date.
Blower Flow: 24 inches of water (vacuum).
Blower Vacuum: 575 scfm.

Gas Vent	Valve Status	Pressure ("H2O)	Gas Vent	Valve Status	Press ("H2O)
1	closed		29	open	
2	closed		30	open	
3	closed		31	open	
4	closed		32	open	
5	closed		33	open	
6	closed		34	open	
7	closed		35	closed	
8	closed		36	open	
9	closed		37	open	
10	closed		38	open	
11	closed		39	open	
12	closed		40	open	
13	closed		41	open	
14	closed		42	open	
15	closed		43	open	-1.0
16	closed		44	open	-2.0
17	closed		45	open	-2.0
18	closed		46	open	-2.0
19	closed		47	open	-2.0
20	open		48	open	-2.0
21	open		49	open	-2.0
22	open		50	open	-2.0
23	closed		51	open	-2.0
24	closed		52	open	-2.0
25	closed		53	open	-2.0
26	open		54	open	-2.0
27	closed		56	open	-2.0
28	open				

Date: 28 Oct 93
Wellfield configuration: Wells #1-25 and 35 closed. All 11-acre gate valves installed as of this date.
Blower Flow: 24 inches of water (vacuum).
Blower Vacuum: 545 scfm.

Gas Vent	Valve Status	Pressure ("H2O)	Gas Vent	Valve Status	Press ("H2O)
1	closed		29	open	
2	closed		30	open	
3	closed		31	open	
4	closed		32	open	
5	closed		33	open	
6	closed		34	open	
7	closed		35	closed	
8	closed		36	open	-12
9	closed		37	open	-13
10	closed		38	open	-12.5
11	closed		39	open	-12.5
12	closed		40	open	-12.5
13	closed		41	open	-13
14	closed		42	open	-2.0
15	closed		43	open	
16	closed		44	open	
17	closed		45	open	
18	closed		46	open	
19	closed		47	open	
20	closed		48	open	
21	closed		49	open	
22	closed		50	open	
23	closed		51	open	
24	closed		52	open	
25	closed		53	open	
26	open	-2.0	54	open	
27	closed		56	open	
28	open				

Date: 19 Nov 93
Wellfield configuration: Wells #1-35 and 42 closed. Drawing from Active tie-in.
Blower Flow: 36 inches of water (vacuum).
Blower Vacuum: 675 scfm.

Gas Vent	Valve Status	Pressure ("H2O)	Gas Vent	Valve Status	Press ("H2O)
1	closed		29	closed	
2	closed		30	closed	
3	closed		31	closed	
4	closed		32	closed	
5	closed		33	closed	
6	closed		34	closed	
7	closed		35	closed	
8	closed		36	open	-8
9	closed		37	open	-8
10	closed		38	open	-8
11	closed		39	open	-8
12	closed		40	open	-8
13	closed		41	open	-8
14	closed		42	closed	
15	closed		43	open	-8
16	closed		44	open	-8
17	closed		45	open	-7
18	closed		46	open	-7
19	closed		47	open	-4
20	closed		48	open	-8
21	closed		49	open	-8
22	closed		50	open	-4
23	closed		51	open	-7
24	closed		52	open	-8
25	closed		53	open	-8
26	closed		54	open	-7
27	closed		56	open	-8
28	closed				

Date: 30 Nov 93
Wellfield configuration: Wells #1-33, 35, 40 and 42 closed. Drawing from Active tie-in. Radius of Influence testing.
Blower Flow: 42.3 inches of water (vacuum).
Blower Vacuum: 723 scfm.

Gas Vent	Valve Status	Pressure ("H2O)	Gas Vent	Valve Status	Press ("H2O)
1	closed		29	closed	
2	closed		30	closed	
3	closed		31	closed	
4	closed		32	closed	
5	closed		33	closed	
6	closed		34	open	-7.0
7	closed		35	closed	
8	closed		36	open	
9	closed		37	open	
10	closed		38	open	
11	closed		39	open	-23
12	closed		40	open	+7
13	closed		41	open	-24
14	closed		42	closed	
15	closed		43	open	
16	closed		44	open	
17	closed	+0.1	45	open	
18	closed		46	open	-9.0
19	closed		47	open	
20	closed		48	open	-11
21	closed		49	open	
22	closed		50	open	-8
23	closed		51	open	
24	closed		52	open	
25	closed		53	open	
26	closed	-0.5	54	open	
27	closed		56	open	
28	closed	+0.1			

Date: 19 Jan 94
Wellfield configuration: All wells open.
Blower Flow: 36.6 inches of water (vacuum).
Blower Vacuum: 700 scfm.

Gas Vent	Valve Status	Pressure ("H2O vac)		Gas Vent	Valve Status	Press ("H2O vac)
1	open	2.9		29	open	2.6
2	open	1.0		30	open	2.4
3	open	1.4		31	open	4.1
4	open	1		32	open	3.4
5	open	0.7		33	open	4.4
6	open	0.3		34	open	4.3
7	open	0.6		35	open	1
8	open	1		36	open	9.6
9	open	1.7		37	open	11.8
10	open	2.6		38	open	12.7
11	open	2.1		39	open	13.6
12	open	1.8		40	open	13
13	open	1.7		41	open	19.9
14	open	1.6		42	open	1.0
15	open	1.9		43	open	10.9
16	open	2.2		44	open	15.4
17	open	1.8		45	open	11.6
18	open	0		46	open	7.1
19	open	0.2		47	open	3.8
20	open	8.4		48	open	6.0
21	open	2.7		49	open	7.6
22	open	2.2		50	open	6.8
23	open	1.3		51	open	15.6
24	open	1.8		52	open	15.6
25	open	1.8		53	open	8.8
26	open	1.8		54	open	11.4
27	open	2.3		56	open	9.9
28	open	2.8				

Gas well concentrations on 19 Jan 94 in the 30-Acre Area:

Gas well #	CH4%	CO2%	O2%	N2%
1	5.5	8.5	14.3	71.5
2	38.7	32.5	0.7	28.1
3	28.4	28.2	2.1	41.0
4	22.9	26.0	2.7	48.7
5	19.2	20.8	7.0	53.0
6	3.0	3.6	18.2	76.4
7	14.6	12.7	13.4	61.2
8	43.8	28.2	4.1	23.9
9				
10	53.0	33.0	0.5	14.5
11	38.9	25.	5.8	30.4
12	32.8	25.4	4.6	36.6
13	27.6	26.5	8.6	42.3
14	3.3	4.6	17.2	75.1
15	5.3	10.5	12.5	71.1
16	38.4	28.5	1.3	31.5
17	22.6	18.4	6.8	52.8
18				
19	1.0	0.6	20.1	78.3
20	45.9	26.7	4.0	24.2
21	19.7	24.0	0.9	55.2
22	40.4	31.6	0	27.0
23	42.0	32.0	0	26.0
24	12.4	12.5	12.8	62.7
25	31.1	31.5	0.1	37.4
26	57.7	41.0	0	1.2
27	57.0	39.0	0	4.0
28	53.1	38.1	0	9.1
29	40.4	28.5	5.6	25.1
30	0.1	0	20.3	79.7
31	0	0	20.3	79.7
32	20.3	13.0	15.7	51.0
33	57.9	36.6	0	5.5
34	46.2	37.6	0.1	16.4
35	12.4	21.3	2.1	64.3
42	45.1	37.5	0	17.2

APPENDIX E

ACCU-FLO WELLHEAD INFORMATION

Methods of LFG Control

The ACCU-Flo Wellhead is a primary tool which can control landfill gas (LFG) surface emissions, migration and extraction on the open or closed landfill.

The quality and quantity of LFG gas extracted from the landfill can indicate the overall decomposition rate and so-called health of the methane producing organisms in the landfill. If a well in the LFG extraction system extracts too much methane, air (oxygen) from the surface of the landfill can be pulled into the landfill killing the methane producing organisms. This stops decomposition until the proper oxygen free environment is re-established. The air can also cause sub-surface fires.

Ask any experienced landfill technician and they will tell you that each landfill is different. Each well has its own characteristics. Unless the correct data is gathered, it is difficult to maximize LFG collection, control emissions and prevent migration at each well location.

There are four generally accepted ways to control landfill gas extraction:

- **Controlling by wellhead vacuum.** The method assumes that wellhead vacuum is directly related to the gas extraction rate.

- **Controlling by wellhead valve position.** Unless the valve handle is pre-calibrated for any given gas flow

[illegible]

rate, this method is unpredictable and should not be relied upon.

- **Controlling by gas composition.** This method measures methane and/or nitrogen (balance gas) concentrations at individual wellheads.
- **Controlling by flow rate.** This is a more exact method for determining proper gas flow adjustments at individual wells.

Well Field Adjustment - Purpose And Objectives

The objective of well field adjustment is to achieve steady state operation of the gas collection system by stabilizing the rate and quality of extracted LFG in order to achieve one or several goals. Typical reasons for recovery of LFG and close control of the well field are:

- Achieve and maintain effective subsurface gas migration control.
- Achieve and maintain effective surface gas emissions control.
- Assist with proper operation of control and recovery equipment.
- Avoidance of well overpull and maintenance of a healthy anaerobic state within the landfill.
- Optimize LFG recovery for energy recovery purposes.
- Control nuisance LFG odors.

- Prevent or control subsurface LFG fires.
- Protect structures on and near the landfill.
- Meet environmental and regulatory compliance requirements.

Well field adjustment is partly subjective and can be confusing because it involves judgment calls based on simultaneous evaluation of several variables as well as general knowledge of site specific field condition and historic trends. Well field evaluation and adjustment consists of a collection of tools and techniques which may be used in combination to achieve steady state well field operation.

Taking Measurements At The Accu-Flo Wellhead

There are two very different ways to take data measurements at an Accu-Flo wellhead -- with LANDTEC's integrated GEM-500 and with individual field instruments. Proceed to the appropriate section below depending on the method used.

Using the GEM-500 to Gather Data

LANDTEC's GEM-500 (Gas Extraction Monitor).

This computerized instrument analyzes and records the methane, carbon dioxide and oxygen content of LFG, measures static and impact pressures, as well as gas temperature. It

calculates Btu content, Btu flow rate, and gas volumetric flow rates. It stores all measured data from each well which can be downloaded to a personal computer.

The GEM-500 was designed specifically for the landfill gas industry and to be used with Accu-Flo Wellheads. The GEM combines may field instruments into one compact instrument which does the following:

- Analyzes % Methane ($CH4$)
- Analyzes % Carbon Dioxide ($CO2$)
- Analyzes % Oxygen ($O2$)
- Calculates % Balance Gas (typically Nitrogen)
- Measures gas pressure
- Measures gas temperature
- Calculates gas Btu
- Calculates dry gas flow automatically from Accu-Flo wellheads
- Built-in computer to analyze and store data
- Built-in RS232 computer interface to download date to PC
- Built-in storage and recall for up to 500 sets of data

These instructions do not go into detail on operating the GEM. Please see the GEM-500 Operating Manual for those procedures. The following assumes Imperial/USA measurements units are used.

When measuring an Accu-Flo Wellhead with a GEM:

1. Remove the dust cap from the Accu-Flo wellhead.

2. Attach the two quick connect fittings on the 1/4th Tygon tubing from the GEM. The chrome fitting goes on the center, impact pressure port which reads the pressure on the impact tube. The almond colored quick connect fitting goes on the outside port for the static pressure.

3. Go to the READ GAS LEVELS MENU on the GEM-500.

4. Answer the next screen's question: "Read Using ID?" 1 - Yes 2 - No (Note: If answer is No, gas samples can be taken be flow cannot be calculated without identifying a well's measurement flow device - Accu-Flo 150, 200, 300; Orifice Plate or Pitot Tube. This is associated with defining a well ID in the GEM.)

5. Using the Blue shift key, toggle between numbers and letters to input the Well ID into the GEM.

6. Turn on the GEM's Pump by Pressing KEY 5 until gas samples stabilize (45 - 120 seconds). Turn pump off (press 5) and press 2 - Continue to next screen for the Pressure and Temperature.

7. On the Pressure/Temperature Screen enter the temperature by reading the temperature on the Accu-Flo Wellhead. Remember to input 3 digits on the GEM. For example, 95°F gas is input as 095 and 125 degree gas as 125.

8. The Static Pressure (SP) and Differential Pressure (DP) should already be displayed if the two GEM hoses are properly connected. If there are problems with the results,

select Zero Pressures from the General Utilities Menu and zero the pressures.

9. The Flow/BTU Screen appears next. The old (the prior reading) flow is displayed on the left side of the tope line in standard cubic feet per minute (SCFM). The new Btu per cubic foot is displayed on the right side. The new flow is displayed on the second line on the left side in SCFM. On the right side is the Btu's per hour.

10. If adjustments are needed, turn the wellhead valve up or down and the screen will dynamically re-display the new flow rate and Btu information.

11. To store the information, press 6 on the GEM-500.

12. Disconnect the hoses from the Accu-Flo wellhead. Press Zero to go back. Run the pump to expel the sample - saving the Oxygen cell from needing adjustment and zero the pressure transducer.

13. Replace the dust cap before going to the next well.

Reading the Accu-Flo Wellhead - Using Standard Field Instruments

To read the Accu-Flo wellhead you will need the following field instruments and equipment:

- Micromanometer or Magnahelic^{tm} able to read pressure or vacuum in inches of water from approximately 0.0 to 80.0, preferably with multiple scales for greater accuracy between 0.0 to 10.00 inches of water.

- Methane Gas Analyzer
- Gas extraction pump to overcome wellhead vacuum
- Accu-Flo Wellhead Flow charts or the Accu-Flow hand held calculator (optional)

When measuring an Accu-Flo Wellhead with standard field instruments:

1. Remove the dust cap from the Accu-Flo wellhead.
2. Attach the two quick connect fittings on the 1/4th tygon tubing from the micromanometer. If differential pressures is to be measured, the fitting on the center of the Accu-Flo wellhead is for the impact pressure port which reads the pressure on the impact tube. The quick connect fitting on the outside port of the wellhead is for the static pressure.
3. Read the static and impact pressure from the wellhead and write them down. The difference between the static and impact pressure is the differential pressure or <u>velocity pressure</u>. It should be a positive number. Remove the micromanometer hoses.
4. Connect the vacuum pump to the wellhead, turn on the vacuum pump and extract LFG samples into a sample bag or LFG container.
5. Analyze the LFG samples for methane and oxygen. Record the results.

6. Read the temperature on the Accu-Flo wellhead of the LFG flowing out of the well. Record the temperature.

7. Determine or Set Gas Flow Rates in the sections below.

8. Replace the dust cap when done.

Determining The Gas Flow Rate

To determine the current gas flow rate (SCFM) of the well, complete the following steps:

1. Use LANDTEC's Flow Charts provided with the wellhead or use the optional LANDTEC hand held Flow Computer. You will need to know the Accu-Flo model wellhead you are using (Model 150, 200, or 300) and its configuration - either Horizontal or Vertical to properly calculate the flow. There are two charts for each model -- one for wet gas and the other for dry gas. To calculate the amount of head (Btu's) in the gas, or do other calculations, the gas is usually converted to the amount of dry gas available. The second chart shows the amount of dry gas at the wellhead.

2. At the end of this manual are copies of all the LFG Flow Charts for the various models and types.

3. Using the appropriate chart, locate the point where the measured velocity pressure (horizontal axis) intercepts the curve on the cart that best approximates the wellhead temperature.

4. Follow across to the left side of the chart entitled, "Flow" (vertical axis) to determine approximate gas flow rate in standard cubic feet per minute (SCFM).

Note: Static pressure is assumed to be one atmosphere when using LANDTEC's SCFM Flow Charts. There is no problem when LANDTEC's GEM-500 and or hand held calculator is used to calculate flow because actual static pressure is used in the calculations.

LANDTEC's Preprogrammed Hand held Calculator (Optional): calculates gas flow rates with greater accuracy and speed than the manual method described above that uses LANDTEC's Accu-Flo SCFM Gas Flow Charts. It uses a user friendly question and answer format and calculates gas flow rates in seconds. The user inputs the model and type of Accu-Flo wellhead, static and impact pressure, and gas temperature and the calculator displays the wet and dry LG\FG flow rate.

Setting Gas Flow Rates

To set the gas flow rate (SCFM) for an Accu-Flo wellhead, complete the steps below. Refer to the procedures for measuring the velocity pressure and wellhead temperature discussing earlier in this section.

1. Determine the desired gas flow rate (SCFM) for the Accu-Flo wellhead.

2. Find LANDTEC's SCFM Flow Chart for the Accu-Flo wellhead model and type of gas flow (wet or dry) provided with the wellhead or at the end of this manual.

3. Find that flow rate on the vertical axis of the flow curve graph. Move across the chart to the right until you intercept the curve that best approximates the wellhead gas temperature at the wellhead. Move down the chart and read the velocity pressure on teh horizontal axis. This is the velocity pressure that must be obtained to get the desired SCFM rate.

4. Following the procedure under Taking Measurements at an Accu-Flo Wellhead, connect the pressure measurement instrument and determine the current <u>velocity pressure</u>.

5. while the pressure measurement instrument is still connected, open or close the valve until the differential (velocity) pressure is obtained that <u>matches</u> the desired SCFM rate.

<u>Other LFG Data</u>

The Accu-Flo wellheads pressure and gas sample ports are located for easy access (See drawing 5 below).

These ports are suitable for sampling concentrations of methane, carbon dioxide and oxygen. These measurements can be accomplished through the appropriate ports using portable electronic equipment that are read in

the field or by using the same ports to extract gas samples to be analyzed by a laboratory or using a gas chromatograph.

The gas temperature information, when compared with historic readings, can show the presence of a nearby underground fire. Gas samples can be tested for the presence of carbon monoxide which removing the impact tube from the wellhead, it can be inspected for soot, which is also another indicator of a nearby underground fire.

Settlement around the well-bore can be the cause of excess oxygen in the LFG, underground fires or surface emissions depending on how the well is being operated.

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BIOGRAPHICAL SKETCH

Kurt R. Gies was born in Buffalo, N.Y. on 15 June 1964 to Walter E. and Yvonne R. Gies. Shortly after his birth he and his family, including three brothers and one sister, moved to the Delray Beach, Fl. where he lived until leaving home for college.

In 1982 he enrolled at the Univeristy of Florida under an United States Naval Scholarship pursing a degree in Mechanical Engineering. In 1987 he was awarded a Bachelor of Science in Mechanical Engineering degree (with Honors) and within hours was commissioned as an Ensign in the United States Navy, Civil Engineer Corps. In 1988, while serving his initial tour as the Director of Engineering for the Naval Training Center, Orlando, Fl. Public Works Department, he married his college sweetheart, the former Peggy Joyce Leiser of Chester Heights, Pa. His second tour was served in New York City as the Project Manager for the Navy's newest strategic homeport. While stationed here he was promoted to his present rank of Lieutenant. In 1992 the Navy directed him to report to the University of Florida as a candidate for a degree of Master of Engineering in Environmental Engineering Sciences. During his time in

school, LT Gies became a registered Professional Engineer in the State of Florida. Additionally,during his time there his wife gave birth to their first child, Matthew "Cory" Gies and later conceieved their second child which is due to arrive in the summer of 1994. Upon graduation LT Gies has orders to report as the Staff Civil Engineer for the Naval Hospital, Pensacola, Fl.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a thesis for the degree of Master of Engineering.

W. Lamar Miller, Chairman
Professor of Environmental
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I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a thesis for the degree of Master of Engineering.

Jonathan F. Earle
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I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a thesis for the degree of Master of Engineering.

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This thesis was submitted to the Graduate Faculty of the College of Engineering and to the Graduate School and was accepted as partial fulfillment of the requirements for the degree of Master of Engineering.

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