

LANDFILL GAS AND GROUNDWATER CONTAMINATION

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ABSTRACT

As landfill gas (LFG) migrates from a landfill, organic contaminants travel with it. These contaminants, commonly referred to as volatile organic compounds (VOCs), have been known to migrate to underlying groundwater. This paper looks at the mechanisms for contamination by LFG constituents and means of controlling it. The four basic mechanisms that cause contamination are:

1. Direct contact of groundwater with LFG,
2. Formation of landfill gas condensate water in the soil outside of a landfill
3. LFG contamination of the vadose zone and infiltration water carrying the VOCs to the groundwater
4. Leachate leaving the landfill and migrating to the groundwater.

Of these four mechanisms, this paper will look at the contamination caused by the first three. These represent methods of groundwater contamination by LFG. Leachate contamination is not within the scope of this paper.

INTRODUCTION

The Resource Conservation and Recovery Act (RCRA) requires that landfill gas (LFG) be controlled so that the concentration of methane at a landfill's property line is less than 5% by volume (*40 CFR Part 258.23*). The purpose of this requirement is to protect adjacent properties from explosive conditions. This requirement does not address the need to control migration due to the presence of Volatile Organic

Compounds (VOCs) in the LFG. The migration of VOCs can cause several problems. First, they can travel to groundwater causing contamination; second, they can infiltrate adjacent structures and potentially cause health risk problems; and third, they can cause odor problems. This paper focuses exclusively on contamination of groundwater by VOCs.

BACKGROUND

LFG testing performed on a number of California landfills demonstrates that most LFG contains some VOCs (3, 4). These contaminants include organic acids, chlorinated hydrocarbons, and numerous other hydrocarbons. The contaminants of greatest concern are typically the chlorinated hydrocarbons. This is because many of the chlorinated hydrocarbons are considered a health risk at low concentrations and because they are not as readily decomposed in the soil by naturally occurring aerobic bacteria. The subsequent movement of these constituents to groundwater can result in concentrations exceeding State or Federal drinking water standards.

Most of the landfills in the U.S. are affected by the presence of VOCs in the underlying groundwater. In a recent study (3) of the results of monitoring RCRA Appendix IX (40 CFR parts 264 and 265) compounds at 479 disposal sites, 84 percent of the detectable compounds were VOCs. The most commonly occurring compounds were the chlorinated hydrocarbons, including the 8 most frequently detected compounds. Methylene chloride was the most commonly detected compound followed closely by trichloroethene and tetrachloroethene. Each of these compounds was detected at over 20% of the landfill sites tested. Because LFG frequently emanates from a landfill into the surrounding soils, there is a possibility that LFG was either the primary source of contamination or a strong contributor. The reason for this assertion is discussed later in this paper.

POTENTIAL FOR CONTAMINATION

Because VOC concentrations vary widely in each landfill, establishing a minimum control level for LFG at the perimeter based on protection of groundwater does not seem practical. (Note: Protection of human health in adjacent structures from VOCs in LFG vapor may be a more significant concern than groundwater at some sites.) Additional factors that can affect the potential for groundwater contamination include LFG generation rates, liner and formation permeabilities, distance to groundwater, and VOC attenuation by soil bacteria. To quantify the mass of contamination that can be discharged from a landfill before experiencing significant groundwater contamination (defined as levels of VOCs in groundwater at or above the MCL) is difficult. Each site is unique and needs to be treated accordingly. In addition, by the time contamination is detected in groundwater monitoring wells a significant amount of VOC mass will likely have accumulated in the unsaturated zone.

The best way to demonstrate the potential for LFG contamination is to describe a typical scenario using several assumptions. Assume a 162,000 sq. meter (40-acre) landfill with 908×10^6 Kg (1,000,000 tons) of refuse in place with an average LFG generation rate of 279 Nm³/Hr (0.25 MM cubic feet per day)¹. (The LFG generation rate is equivalent to an annual LFG yield of 0.00265 Nm³/Kg (0.045 cubic feet per pound of refuse).) The gas is assumed to contain 10 ppmv trichloroethene (TCE) as its only contaminant. (TCE was selected because it is frequently found in groundwater (3).) Assuming 10% of the LFG with its VOC fraction goes into the vadose zone and 10% of this eventually reaches groundwater. The magnitude of contamination of trichloroethene VOC is calculated by determining the resulting volume of groundwater that would be effected by the contamination. The potential contaminated water volume is estimated by limiting the average contamination in the water to the MCL for TCE. The procedure used in Equation 1 is to first determine the lbs. of TCE in groundwater and divide this by the MCL of TCE to yield the water contamination volume.

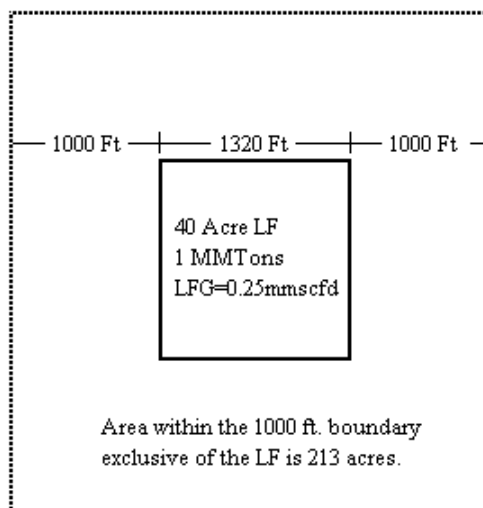


Figure 1: Example Landfill With 1000 Ft Border

$$\begin{aligned}
 V &= (0.1)(0.1) \left(\frac{10 \text{ ppmv}}{1 \times 10^6} \right) \left(\frac{279 \frac{\text{Nm}^3}{\text{Hr.}} \times 24 \frac{\text{Hr.}}{\text{Day}}}{\frac{22.4 \text{ L}}{\text{g-mole}} \times \frac{1 \text{ m}^3}{1000 \text{ L}}} \right) \left(\frac{131 \text{ g-TCE}}{\text{g-mole}} \right) \left(\frac{\text{L}}{5 \text{ mg}} \right) \left(\frac{1 \times 10^6 \text{ mg}}{\text{g}} \right) \left(\frac{365 \text{ Days}}{\text{Yr.}} \right) \quad (1) \\
 &= 286 \times 10^6 \frac{\text{L}}{\text{Yr.}} \quad (75 \times 10^6 \text{ gallons/Yr.})
 \end{aligned}$$

where;

- V = Contaminated Water Volume at the MCL
- 10 ppmv = assumed volume concentration of TCE in LFG
- 5 µg/L = drinking water Maximum Contaminant Level for TCE (5 ppbw)

¹ Standard conditions used in calculations are 0°C and 760 mm Hg for metric units and 60°F and 14.7 psia for English units.

This annual volume of contaminated water would cover an area of approximately 142,000 m² (115 acres), assuming a 3.05 m (10 foot) thickness of uniformly contaminated aquifer and a 0.20 soil porosity.

Landfill liners provide only a partial barrier to LFG movement. Clay-lined landfills are subject to the same convective and diffusive mechanisms as an unlined landfill. Geomembrane liners are subject to construction deficiencies and deterioration. As an example of the magnitude of potential migration through a clay liner, consider the example of only diffusive transport of TCE through a typical landfill liner (1).

$$Q = \frac{AD\alpha^{4/3}C_i - C_w}{L} \quad (2)$$

where;

- Q = Diffusive flow of TCE
- A = Area of landfill bottom (40 acre landfill)
- D = Diffusion coefficient of TCE at 20°C
- $\alpha^{4/3}$ = Gas filled porosity of liner (assumed no saturation)
- C_i = Concentration of TCE above liner (10 ppmv)
- C_w = Concentration of TCE below liner (9.99 ppmv)
- L = Depth of liner

$$Q_{TCE} = \frac{(162,000 \text{ m}^2) \left(\frac{10,000 \text{ cm}^2}{\text{m}^2} \right) \left(\frac{0.067 \text{ cm}^2}{\text{sec.}} \right) (0.20)^{4/3} \left(\frac{10 - 9.99}{1,000,000} \right) \left(\frac{131 \text{ g}}{\text{g - mole}} \right) \left(\frac{1 \text{ g - mole}}{22.4 \text{ L}} \right) \left(\frac{1 \text{ L}}{1000 \text{ cm}^3} \right) \left(\frac{86,400 \text{ sec.}}{\text{day}} \right)}{61 \text{ cm}} \quad (3)$$

= 1.05 g/day TCE

and

$$V = \left(1.05 \frac{\text{gTCE}}{\text{Day}} \right) \left(\frac{365 \text{ Days}}{\text{Yr.}} \right) \left(\frac{1}{5 \text{ mg}} \times \frac{1 \times 10^6 \text{ mg}}{1 \text{ g}} \right)$$

= 77 x 10⁶ L/Yr. (20 x 10⁶ gallons/Yr.)

LFG CONTAMINATION MECHANISMS

The three basic mechanisms which cause groundwater contamination by VOCs in LFG within the vadose zone are described briefly in this section and are shown on **Figure 2**, LFG Contamination Mechanisms.

1. Direct contact with groundwater by LFG.

LFG migrating from a site tends to travel the path of least resistance. Generally that path is towards the atmosphere. Two dimensional modeling also shows that LFG migrates downward prior to escaping to the atmosphere. As LFG reaches the capillary zone, the VOCs in the LFG have a good opportunity to be absorbed into the groundwater.

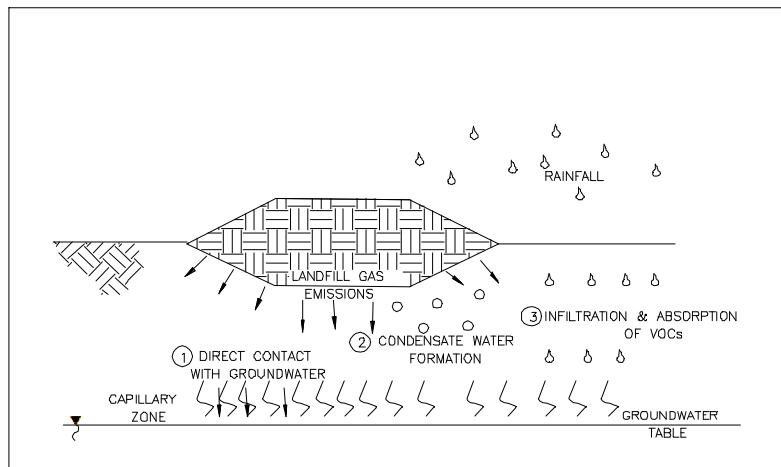


Figure 2: LFG Contamination Mechanisms

2. Formation of landfill gas condensate in the soil adjacent to the landfill.

Landfill gas temperatures typically range from 27 to 38° C (80 to 100° F) within a landfill. As LFG moves through refuse, it is typically saturated with water at these temperatures. The soil surrounding a landfill is usually cooler, and for discussion purposes is assumed to be 16° C (60° F). The difference in these two conditions will result in the formation of condensate water outside the refuse mass. Partitioning of VOCs from the vapor to liquid phase will typically result in trace concentrations of VOCs within the condensate.

3. LFG contamination of the vadose zone and infiltration water carrying the VOCs to the groundwater

As LFG migrates through the soil adjacent to a landfill, VOC mass adheres to the soil matrix in either vapor or liquid phase. As rainwater, irrigation or other water infiltrates from above, it reaches equilibrium with the VOCs present in the soil. Provided these VOCs are not consumed by bacteria or stripped from the water, they may eventually reach groundwater.

Henry's Law

The three mechanisms described above are all based on absorption of the VOCs from the vapor phase to the liquid phase. The magnitude of the equilibrium absorption and the resulting relative equilibrium concentrations of the VOCs in the air and water phases can be calculated using Henry's Law. Henry's law is expressed as follows:

$$X_{AQ} = \frac{P_x}{K} \quad (4)$$

where;

X_{AQ} = Aqueous concentration of the gas
 K = Henry's Law constant at specified temperature
 P_x = Partial pressure of the gas

To demonstrate the partitioning of VOC between the water phase and the vapor phase, LFG is assumed to contain trichloroethene, benzene and vinyl chloride as the only contaminants. The assumed gas phase concentration of each is 1 ppmv and the absorption of each does not hinder the absorption of the others.

A. Benzene Concentration in Water:

$$X_B = \frac{1 \times 10^{-6} (1 \text{ atm} - 0.0313 \text{ atm})(78 \text{ g/g}^* \text{ mol})(1 \times 10^6 \text{ mg/g})}{(5.43 \times 10^{-3} \text{ m}^3 \text{ atm/g}^* \text{ mol})(1000 \text{ L/m}^3)} \quad (5)$$

= 13.9 $\mu\text{g/L}$ Benzene (Note: MCL for Benzene = 1 $\mu\text{g/L}$)

where;

K = $5.43 \times 10^{-3} \text{ m}^3 \text{ atm/g}^* \text{ mol}$ is the Henry's Law constant for Benzene at 20°C
 $78 \text{ g/g}^* \text{ mol}$ = the molecular weight of Benzene
 0.0313 atm = the correction for the vapor pressure of water

B. TCE Concentration in Water:

$$X_{TCE} = \frac{1 \times 10^{-6} (1 \text{ atm} - 0.0313 \text{ atm})(131.4 \text{ g/g}^* \text{ mol})(1 \times 10^6 \text{ mg/g})}{(1.03 \times 10^{-2} \text{ m}^3 \text{ atm/g}^* \text{ mol})(1000 \text{ L/m}^3)} \quad (6)$$

= 12.3 $\mu\text{g/L}$ TCE (Note: MCL for TCE = 5 $\mu\text{g/L}$)

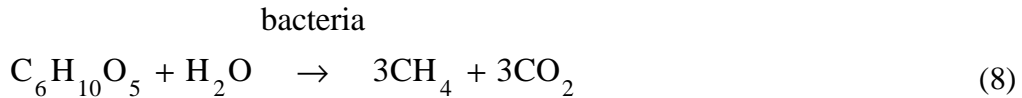
C. Vinyl chloride Concentration in Water:

$$X_{vc} = \frac{1 \times 10^{-6} (1 \text{ atm} - 0.0313 \text{ atm})(62.5 \text{ g} / \text{g} * \text{mol})(1 \times 10^6 \mu\text{g} / \text{g})}{(1.07 \times 10^{-2} \text{ m}^3 \text{ atm} / \text{g} * \text{mol})(1000 \text{L} / \text{m}^3)} \quad (7)$$

$$= 5.8 \mu\text{g/L Vinyl Chloride} \quad (\text{Note: MCL for VC} = 0.5 \mu\text{g/L})$$

LANDFILL GAS GENERATION

Landfill gas is generated by the decomposition of refuse by anaerobic bacteria. A simple equation for the production of LFG from cellulose is as follows:



Because LFG is primarily generated by the decomposition of solids in the refuse, the resulting gas occupies a substantially larger volume than the refuse. This causes pressure to build within the landfill as the gas tries to expand to its natural volume. The level of pressure developed is a function of the tortuosity and restrictions the gas has to travel through to expand within the refuse. This process creates the pressure for convective movement of LFG in soil.

The magnitude of pressures typically found at the bottom of a landfill have been measured at pressures ranging from low levels of less than one inch of water column to as high as 4 atmospheres (Operating Industries landfill, Monterey Park, California). The conditions that cause high pressures usually include deep and wet refuse and low permeable soil (1×10^{-6} cm/sec or less) surrounding the landfill.

If LFG is under pressure, it can migrate great distances due to convective transport. Circumstances that allow migration often include highly permeable strata sandwiched between less permeable material. This can also include the sand bedding used to backfill utility pipes and other man-made fills. Many sites have shown measurable concentrations of the constituents of LFG as much as a thousand feet from the site.

MAGNITUDE OF CONTAMINATION MECHANISMS

In order to design a control strategy for minimizing the amount of VOC mass migrating from a landfill, the unique characteristics of each site must be considered. However, it is useful to look at the relative contributions from each of the previously described mechanisms. Evaluation of the potential for VOC migration from condensate formation and vapor phase transport are discussed below.

Condensate Water Formation

The amount of water condensing from LFG is primarily a function of temperature differences. A simple equation used to calculate the amount of water that is present in LFG is based on the partial pressure of the water.

$$H_2O \% = \left(\frac{ppH_2O}{P_T} \right) \times 100 \quad (9)$$

where;

ppH₂O = Partial Pressure of the water (Water vapor pressure)
P_T = System total pressure

The amount of water that condenses is calculated by determining the water content of the LFG in the landfill and again within the soil. The difference between these values is equal to the water that condenses. For the example given previously, if 10% of 0.25 mm of dry LFG exits the landfill at 32° C (90° F) and cools to 16° C (60° F) in the soil with a system pressure of 760 mm Hg (14.7 PSIA), the amount of water that condenses is calculated:

$$\text{Volume of Water in LFG (Nm}^3\text{)} = \frac{H_2O \% \times \text{LFG (Nm}^3\text{)}}{(1 + H_2O \%)} \quad (10)$$

The fraction of water in the landfill gas while it is in the landfill and in the soil is calculated.

$$H_2O \% \text{ at } 32^\circ \text{C} = \left(\frac{15.1 \text{ mm Hg}}{760 \text{ mm Hg}} \right) \times 100 = 2\% \quad (11)$$

$$H_2O \% \text{ at } 16^\circ \text{C} = \left(\frac{2.64 \text{ mm Hg}}{760 \text{ mm Hg}} \right) \times 100 = 0.34\% \quad (12)$$

Therefore water condensate formation ΔW (Nm³)

$$\Delta W = \left[\frac{0.02 \times (0.1 \times 279 \text{ Nm}^3 / \text{Hr.})}{(1 + 0.02)} - \frac{0.0034 \times (0.1 \times 279 \text{ Nm}^3 / \text{Hr.})}{1 + 0.0034} \right] \times \left(\frac{24 \text{ Hr.}}{\text{Day}} \right) \quad (13)$$

$$\Delta W = 10.86 \frac{\text{Nm}^3 \text{ Water Vapor}}{\text{Day}} \rightarrow 8.73 \frac{\text{L}}{\text{Day}}$$

Based on previous Henry's Law calculations, the TCE mass present in the condensate water is approximately:

$$\text{TCE} = 8.73 \frac{\text{L}}{\text{Day}} \times 12.2 \frac{\text{mg}}{\text{L}} = 107 \frac{\text{mg}}{\text{Day}} \quad (14)$$

The annual volume of groundwater that would be contaminated by this is calculated:

$$\begin{aligned} V &= \left(107 \frac{\text{mg}}{\text{Day}} \right) \left(365 \frac{\text{Days}}{\text{Yr.}} \right) \left(\frac{\text{L}}{5\text{mg}} \right) \\ &= 7811 \frac{\text{L}}{\text{Yr.}} \end{aligned} \quad (15)$$

This calculation shows that condensate water does not appear to be a major contamination mechanism. Compared to the potential to contaminate calculation (Equation 1), this is a small quantity.

Vapor Phase Contamination

Vapor phase contamination occurs by two processes. These are direct contact of LFG with groundwater and leaching of VOCs from the vadose zone by infiltrating water. Because of the potential magnitude of VOCs in the soil, these combined mechanisms have the opportunity to cause the most water contamination. Both of these mechanisms are enhanced by the tendency of LFG to travel both vertically and laterally away from the landfill. By distributing the VOCs into a larger area there is increased opportunity for water infiltration or VOC diffusion to groundwater to cause contamination.

Consider the sample landfill shown on **Figure 1**. If we assume that VOCs migrate laterally due to convective transport, the areal extent of contamination outside the landfill is estimated to be 213 acres. The 1000 ft. border is selected because this is a commonly established regulatory guideline for LFG emissions.

The contribution of each mechanism is not quantified because these would be very specific to the site under consideration. The contribution of each could range from small to large depending on the water infiltration rate, proximity to groundwater and other geologic factors and conditions. The combination of these processes may contribute significantly to future water contamination even if the contamination source is controlled. This is because of residual VOC's in the vadose zone that can migrate to groundwater.

PROTECTION OF GROUNDWATER

Protecting groundwater from LFG contamination is best achieved by containing LFG within the landfill. Landfills often times have gas control systems present within them. Taking advantage of these systems to help protect groundwater is not a common function. A more common practice is to control methane gas at the landfill's perimeter. This type of approach misses a great opportunity to help protect the environment and reduce the potential of future groundwater clean-up.

The scope of this paper does not include presenting operational and design procedures for minimizing the amount of VOCs escaping from the landfill. Mitigation of VOCs once they reach the unsaturated zone beneath a landfill are discussed briefly. Two methods for reducing the capacity of VOCs to migrate to groundwater from the unsaturated zone are as follows:

1. Increase Volatilization of VOCs in the Unsaturated Zone

The process of removing VOCs from soil has been used extensively to remediate contaminated soils. This process flushes the soil with stripping air to evaporate the VOCs. This process is also supplemented by bacterial degradation of the VOCs in an aerobic environment. Not all VOCs are easily decomposed by aerobic bacterial. For these stripping will be the primary mechanism for removal.

The process commonly used to strip VOC's from the soil is the installation of gas extraction wells. Wells may be placed inside or outside the refuse mass. Because of the potential for wells located outside the refuse to pull VOCs from the landfill however, these need to be used cautiously so as not to increase the contamination area.

Using wells within the refuse is a preferred technique. In addition to controlling LFG emissions, this process can also be used to remove VOCs from the vadose zone. The difficulty with this is preventing landfill fires which result from excessive gas extraction rates.

2. Insitu Degradation of VOCs in the Unsaturated Zone

The second method to reduce VOCs is to degrade them with bacteria. Methaotrophic degradation of chlorinated hydrocarbons can be reasonably effective. In this process, the methane present in the landfill gas is used as a fuel source. Enzymes excreted by the bacteria can co-metabolize the chlorinated hydrocarbons (2). The difficulty with this process is making sure sufficient methane and oxygen are present to oxidize residual VOCs. Operation of perimeter wells will create an aerobic environment. This is suitable for bacterial decomposition of most non-chlorinated hydrocarbons. However, chlorinated hydrocarbons

decompose slowly in an aerobic environment. Ultimately the solution is to prevent VOCs migration into the vadose zone in the first place.

CASE HISTORY: ELSINORE LANDFILL

The Elsinore Landfill, located in Lake Elsinore, CA is an unlined, former Class III (municipal waste) landfill which was closed in 1986. The 44 acre site received approximately 543,000 m³ (710,000 cubic yards) of refuse between 1953 and 1986. The landfill is located in an arid environment with an average annual ambient temperature of 17° C (63° F) and an average annual rainfall of less than 38 cm (15 inches) per year. Average depth to groundwater below the landfill is approximately 15.24 m (50 feet). The landfill was capped with two feet of clay in 1992.

The anticipated volume of leachate generation in this environment is relatively small, and in fact drilling in the refuse mass which took place in 1992 indicated a relatively dry refuse. Ongoing quarterly monitoring at the site does not indicate leachate contamination of the underlying groundwater. A good indicator of leachate contamination, chloride, does not exhibit any statistically significant increase in downgradient concentrations of chloride versus upgradient concentrations.

Groundwater monitoring has indicated a number of volatile organic compounds (VOCs) both upgradient and downgradient of the landfill. **Table 1** is a summary of all detected compounds in the groundwater monitoring wells located at the site. Because the surrounding land use is a wildlife habitat, it is probable that the landfill is the source of VOC contamination. The apparent source of contamination is via two mechanisms described previously, condensate formation and migration in the liquid phase or direct contact of LFG constituents with groundwater and subsequent air/liquid phase partitioning. Leachate is not considered a mechanism because of the dry refuse state.

The expected volume of selected VOCs from condensate formation were conservatively calculated based on the known flow rate of LFG, VOC concentrations in LFG, LFG cooling of -1° C (30° F), and complete migration of the condensate to groundwater (no attenuation, degradation, or retardation). The calculated volume of these VOC constituents in the condensate water do not support the measured concentrations in the groundwater.

A landfill gas collection system was installed to reduce methane concentrations in the perimeter probes and to help the groundwater contamination problem. A layout of the landfill and collection system is shown on **Figure 3**.

Following installation of the LFG system the methane concentration in the perimeter probes decreased to acceptable levels. Additionally, the VOC concentration in the groundwater wells showed a slight decrease.

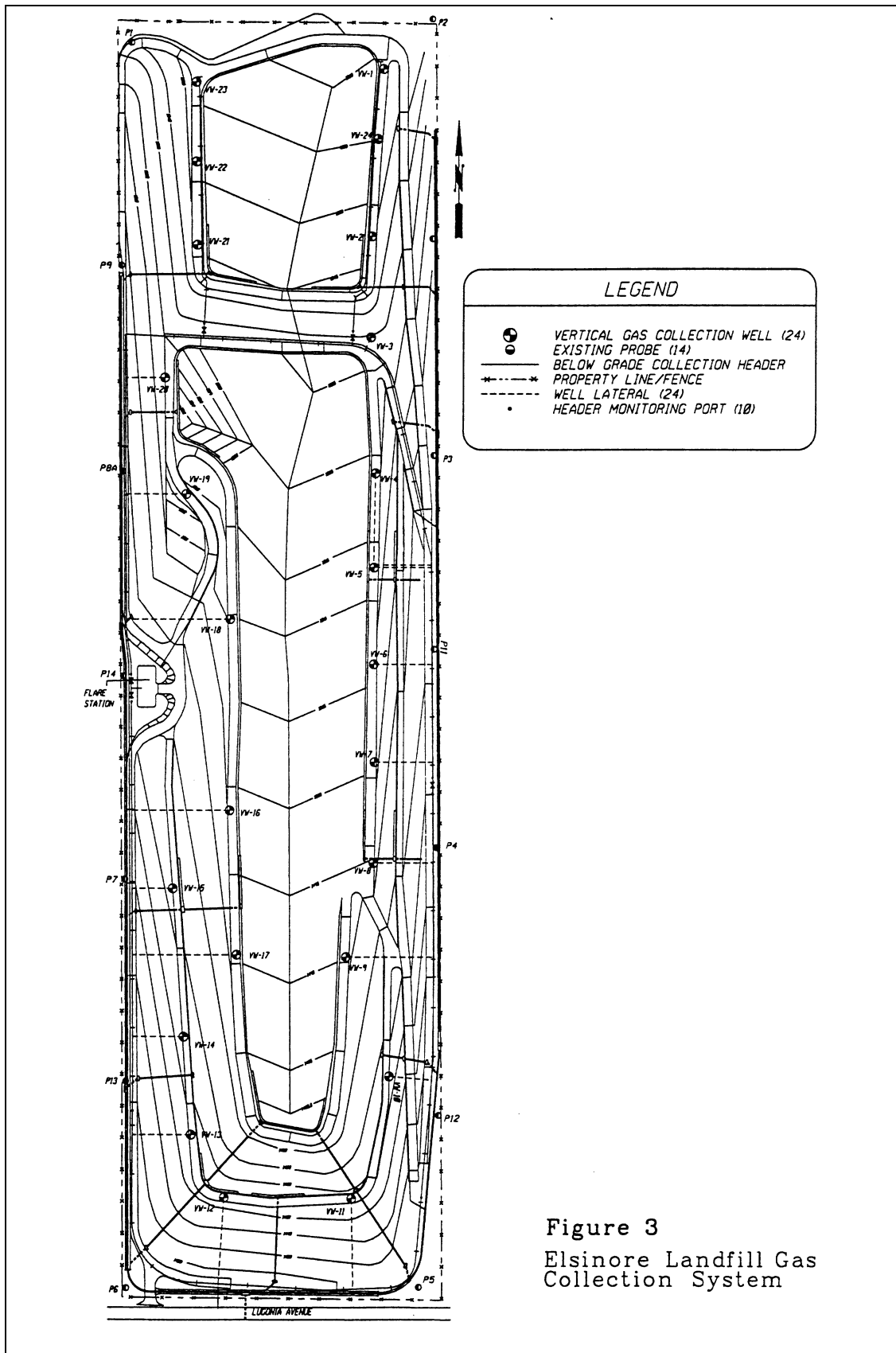
The evidence suggests that the LFG collection system had an impact on the VOC present in the groundwater. This system was able to control the methane concentration at the landfill's perimeter and cause a small reduction in the VOCs concentrations in the groundwater. Because of expected VOCs reservoirs in the vadose zone caused by years of uncontrolled LFG emissions, it is expected to take years to demonstrate VOCs control and protection of groundwater.

TABLE 1

SUMMARY OF DETECTED COMPOUNDS IN THE GROUNDWATER MONITORING WELLS

Elsinore Sanitary Landfill
Summary of Detected Parameters (1st Quarter 1995)

Well ID: E-1	Well ID: E-2	Well ID: E-3	Well ID: E-4
Date Sampled: 2/18/95	Date Sampled: 2/18/95	Date Sampled: 2/18/95	Date Sampled: 2/18/95
Ammonia (NH ₃)	0.004 mg/L	1.7 mg/L	0.025 mg/L
Ammonium (NH ₄)	0.018 mg/L	0.13 mg/L	0.1 mg/L
Barium (Ba)	0.078 mg/L	0.71 mg/L	0.001 mg/L
Benzothiazole (BTZ)	3.1 mg/L	0.008 mg/L	
Boron (B)	0.11 mg/L	0.033 mg/L	
Calcium (Ca)	7.1 mg/L	2.9 mg/L	
Chloride (Cl)	45.8 mg/L	0.005 mg/L	
Copper (Cu)	0.005 mg/L	1.47 mg/L	
Fluoride (F)	0.21 mg/L	0.74 mg/L	
Iron (Fe)	7.5 mg/L	0.003 mg/L	
Magnesium (Mg)	14.3 mg/L	1.7 mg/L	
Manganese (Mn)	0.007 mg/L	0.76 mg/L	
Mercury (Hg)	0.0002 mg/L	0.003 mg/L	
Molybdenum (Mo)	0.014 mg/L	0.76 mg/L	
Nickel (Ni)	0.008 mg/L	18.9 mg/L	
Nitrate (NO ₃ -N)	10.8 mg/L	0.005 mg/L	
Phosphorus (P)	3.3 mg/L	0.007 mg/L	
Selenium (Se)	0.007 mg/L	0.007 mg/L	
Sulfate (SO ₄)	32.8 mg/L	0.014 mg/L	
Specific Conductance	337 micromhos/cm	0.004 mg/L	
Solids (TSS)	40.7 mg/L	2.8 mg/L	
Total Dissolved Solids	204 mg/L	4.1 mg/L	
Total Hardness	244 mg/L	48.9 mg/L	
Total Organic Carbon (TOC)	2 mg/L	13.0 mg/L	
Total Phosphorus (P)	0.051 mg/L	1.4 mg/L	
Vanadium (V)	0.008 mg/L	0.1 mg/L	
Zinc (Zn)		0.008 mg/L	
1,1-Dichloroethane		1.7 mg/L	0.025 mg/L
1,2-Dichloroethane		0.13 mg/L	0.1 mg/L
1,1,1-Trichloroethane		0.71 mg/L	0.001 mg/L
1,1,2-Dichloroethane		0.008 mg/L	
Acetone (Me ₂ C=O)		0.033 mg/L	
Benzene (C ₆ H ₆)		2.9 mg/L	
Bromobenzene (C ₆ H ₅ Br)		0.005 mg/L	
Chlorobenzene (C ₆ H ₅ Cl)		1.47 mg/L	
1,1,2,2-Tetrachloroethane		0.74 mg/L	
1,1,1,2-Tetrachloroethane		0.003 mg/L	
1,1,2,2-Tetrachloroethane		0.76 mg/L	
1,1,1-Trichloroethane		18.9 mg/L	
1,2-Dichloroethane		0.005 mg/L	
1,1,2,2-Tetrachloroethane		0.007 mg/L	
1,1,1-Trichloroethane		0.014 mg/L	
1,2-Dichloroethane		0.004 mg/L	
1,1,1,2-Tetrachloroethane		2.8 mg/L	
1,1,2,2-Tetrachloroethane		4.1 mg/L	
Acetone (Me ₂ C=O)		48.9 mg/L	
Benzene (C ₆ H ₆)		13.0 mg/L	
Bromobenzene (C ₆ H ₅ Br)		1.4 mg/L	
Chlorobenzene (C ₆ H ₅ Cl)		0.1 mg/L	
1,1,2,2-Tetrachloroethane		0.005 mg/L	
1,1,1-Trichloroethane		0.004 mg/L	
1,2-Dichloroethane		2.8 mg/L	
1,1,2,2-Tetrachloroethane		4.1 mg/L	
Acetone (Me ₂ C=O)		48.9 mg/L	
Benzene (C ₆ H ₆)		13.0 mg/L	
Bromobenzene (C ₆ H ₅ Br)		1.4 mg/L	
Chlorobenzene (C ₆ H ₅ Cl)		0.1 mg/L	
1,1,2,2-Tetrachloroethane		0.005 mg/L	
1,1,1-Trichloroethane		0.004 mg/L	
1,2-Dichloroethane		2.8 mg/L	
1,1,2,2-Tetrachloroethane		4.1 mg/L	
Acetone (Me ₂ C=O)		48.9 mg/L	
Benzene (C ₆ H ₆)		13.0 mg/L	
Bromobenzene (C ₆ H ₅ Br)		1.4 mg/L	
Chlorobenzene (C ₆ H ₅ Cl)		0.1 mg/L	
1,1,2,2-Tetrachloroethane		0.005 mg/L	
1,1,1-Trichloroethane		0.004 mg/L	
1,2-Dichloroethane		2.8 mg/L	
1,1,2,2-Tetrachloroethane		4.1 mg/L	
Acetone (Me ₂ C=O)		48.9 mg/L	
Benzene (C ₆ H ₆)		13.0 mg/L	
Bromobenzene (C ₆ H ₅ Br)		1.4 mg/L	
Chlorobenzene (C ₆ H ₅ Cl)		0.1 mg/L	
1,1,2,2-Tetrachloroethane		0.005 mg/L	
1,1,1-Trichloroethane		0.004 mg/L	
1,2-Dichloroethane		2.8 mg/L	
1,1,2,2-Tetrachloroethane		4.1 mg/L	
Acetone (Me ₂ C=O)		48.9 mg/L	
Benzene (C ₆ H ₆)		13.0 mg/L	
Bromobenzene (C ₆ H ₅ Br)		1.4 mg/L	
Chlorobenzene (C ₆ H ₅ Cl)		0.1 mg/L	
1,1,2,2-Tetrachloroethane		0.005 mg/L	
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1,1,2,2-Tetrachloroethane			



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KEY WORDS

- Landfill Gas
- Contamination
- Groundwater
- Volatile Organic Compounds
- Vinyl Chloride
- TCE
- Landfill
- Leachate