ARCS V

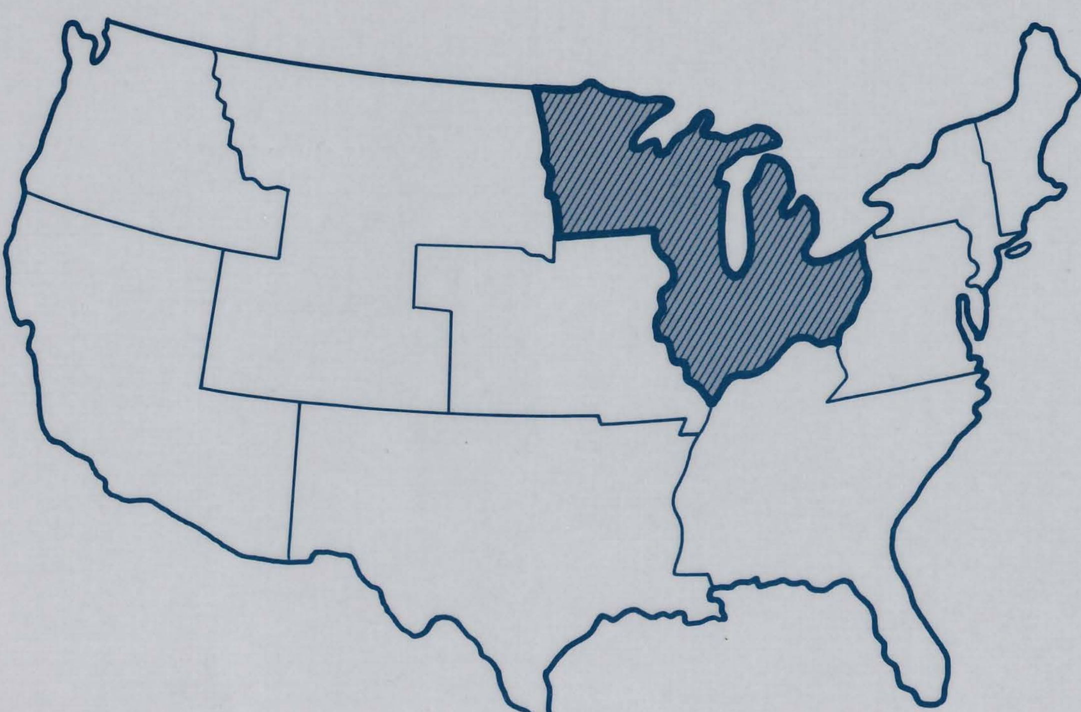
Remedial Activities at Uncontrolled Hazardous Waste Sites in Region V

EPA United States Environmental Protection Agency

In Situ Bioremediation Startup Report
Onalaska Municipal Landfill

WA No. 47-5RL5

September, 1994



CH2M HILL

In Situ Bioremediation Startup Report Onalaska Municipal Landfill

WA No. 47-5RL5

September, 1994

Submitted to U.S. EPA Region 5
By

CH2M HILL

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MKE10014D9A.WP5/1

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Section 1
Introduction

Purpose of the Report

The Onalaska Municipal Landfill in situ bioremediation system (bioventing system) was placed into operation in late May 1994. This report presents a brief summary of the operations and data collected and an interpretation of the data. The report will serve as a basis for directing future bioventing operations at the landfill.

Background

The Onalaska Municipal Landfill site is located in Onalaska Township, a rural area near La Crosse, Wisconsin. It consists of a former municipal landfill about 8 acres in area and adjacent property where the groundwater contamination plume has migrated. The site was operated from the 1960s to the 1970s as a sand and gravel quarry. Industrial wastes, including naphtha-based solvents, were disposed of at the site.

Investigations conducted at the site in 1989 found that the groundwater is contaminated, primarily with volatile organic compounds (VOCs), and that groundwater contaminants are migrating toward the Black River. The investigations also determined that a 3- to 5-foot layer of soil in the vadose zone immediately above the water table and downgradient from the landfill is contaminated with petroleum hydrocarbon solvents. Much of the hydrocarbon contamination appears to be related to the naphtha disposed of at the site. The hydrocarbons migrated out of the disposal area and smeared through the vadose zone soil with fluctuations in groundwater elevation. The zone of nonaqueous phase liquid (NAPL) contamination extends over an area estimated to be more than 4 acres within and immediately southwest of the landfill. The 2 to 2.5 acres of contamination that extend beyond the landfill are targeted for in situ bioremediation. The depth to the NAPL contamination is about 8 to 12 feet in this area. It was not considered technically feasible to address the contamination within the landfill through in situ methods because of the potential for aerobic subsurface conditions to cause landfill smoldering. Figure 1-1 presents the estimated extent of the NAPL contamination.

As described in the feasibility study for cleanup of the site, the in situ bioremediation system was to consist of the injection of air into the NAPL contamination to stimulate the naturally-occurring aerobic microbes and so affect a higher rate of contaminant biodegradation. This technology is typically referred to as bioventing.

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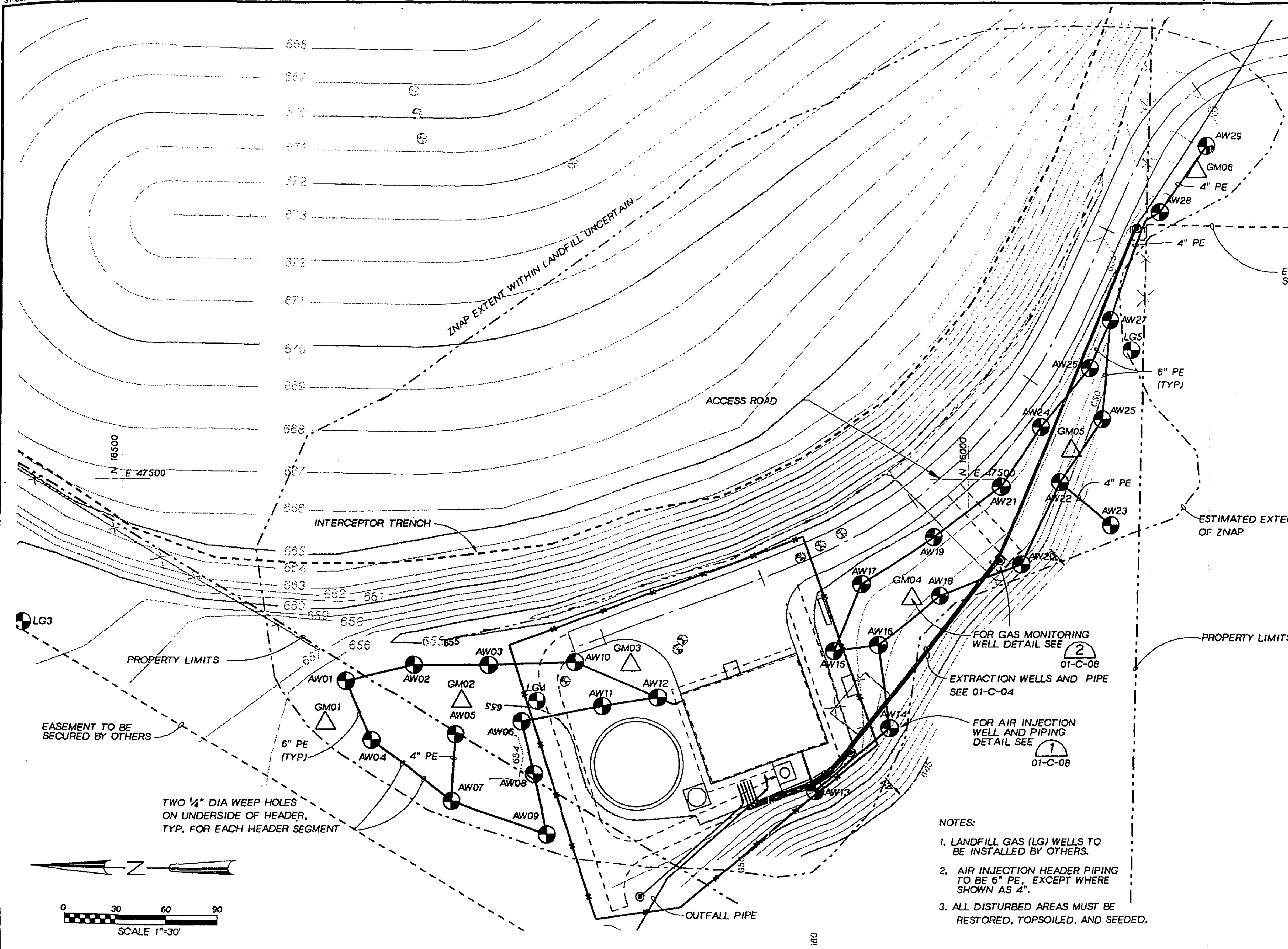

NOTES:

1. LANDFILL GAS (LG) WELLS TO BE INSTALLED BY OTHERS.
2. AIR INJECTION HEADER PIPING TO BE 6" PE, EXCEPT WHERE SHOWN AS 4".
3. ALL DISTURBED AREAS MUST BE RESTORED, TOPSOILED, AND SEEDED.

Coordinates for Air Injection and Gas Monitoring Wells

Wells	Northing	Easting
AW01	16367	47380
AW02	16327	47390
AW03	16282	47390
AW04	16351	47346
AW05	16302	47349
AW06	16263	47357
AW07	16305	47310
AW08	16256	47326
AW09	16248	47290
AW10	16232	47391
AW11	16216	47366
AW12	16183	47371
AW13	16089	47316
AW14	16046	47353
AW15	16078	47398
AW16	16052	47402
AW17	16062	47437
AW18	16016	47431
AW19	16020	47465
AW20	15969	47449
AW21	15980	47495
AW22	15946	47498
AW23	15915	47472
AW24	15957	47530
AW25	15920	47535
AW26	15928	47565
AW27	15915	47593
AW28	15886	47657
AW29	15859	47696
GM01	16379	47357
GM02	16298	47370
GM03	16199	47392
GM04	16033	47431
GM05	15939	47518
GM06	15864	47683

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NO.	DATE	REVISION	BY	APVD

CH2M HILL

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GROUNDWATER REMEDIAL ACTION

ONALASKA MUNICIPAL LANDFILL SITE
ONALASKA TOWNSHIP, WISCONSIN

Figure 1-1
Air Injection Header Piping and Well Location Plan

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DATE	OCT 1992
PROJ NO.	GLO65602.FD

Section 2
Remedial Action Goals

The in situ treatment system is designed to enhance the degradation of organic contaminants in the vadose zone immediately downgradient from the landfill. This area is known as the zone of NAPL contamination. No treatment standards or health-based cleanup criteria have been established for NAPL-contaminated soil at this site. However, the ROD defines a cleanup goal of 80 to 95 percent reduction of the organic contaminant mass in the soils. The organic contaminant mass is the petroleum-based and petroleum-related constituents in the soil. Because the NAPL contamination could act as a source of benzene, toluene, ethylbenzene, and xylene (BTEX) contaminants in groundwater, a secondary goal of the treatment system is to reduce the BTEX contaminant loading to the groundwater. No specific time has been established for accomplishment of the remedial action goals, although the ROD specifies that in situ bioremediation be performed for at least two 200-day treatment seasons.

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Section 3
Treatment System Description

The objective of the treatment system is to inject air into the zone of NAPL contamination at a rate that maintains aerobic conditions within the soil. However, the air injection will be kept to a minimum to limit the potential for aeration of waste within the landfill, drying of the soil, and volatilization of organic contaminants.

The treatment system consists of 29 vertical air injection wells (AW-01 through AW-29) connected by a header piping network supplied with air from a single aeration well blower. The 2-inch-diameter air injection wells are spaced on 40- to 50-foot centers throughout the NAPL zone and installed with the screened interval spanning the 3- to 5-foot-thick NAPL layer. Each well is connected to the header piping by a lateral pipe with a valve that is used to modulate the air supply to specific areas in response to the rate of oxygen consumption in each area. The system is designed to provide 100 to 420 standard cubic feet per minute (scfm) of air to maintain aerobic conditions throughout the zone of NAPL contamination. Figure 1-1 shows the layout of the treatment system.

Six soil gas probe nests (GM-01 through GM-06) with two probes per nest are installed between the injection wells (Figure 1-1). The probes are used to measure soil gas pressure and to withdraw soil gas samples for oxygen, carbon dioxide, methane, and vapor phase hydrocarbon analyses. The probes are constructed of 1-inch-diameter Schedule 40 PVC pipe and have 1 foot of well screen. At each nest, one probe is placed at the bottom of the NAPL zone and one at the top. Both probes are encased in a 6-inch-diameter outer casing for protection.

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Section 4
Summary of System Startup and Initial Performance

The objectives for the bioventing system startup and initial operations were to:

- Evaluate initial soil gas conditions before system startup
- Verify that the design flow and injection pressures are sufficient to aerate the vadose zone soil
- Balance flows between the various air injection wells
- Perform initial oxygen uptake (soil respiration) studies to assess the rate of hydrocarbon degradation

The results for each of these will be presented in more detail in the following sections.

Prestartup soil gas sampling was completed May 18 through 20, 1994, and bioventing system startup was on May 24. From May 24 through June 16, the injection flows were measured several times and balanced between the wells. The bioventing system has been running almost continuously since June 16. Air flow rates and soil gas pressures are assessed every 1 to 2 weeks.

Initial Soil Gas Sampling

Analyses of the soil gas composition (oxygen, carbon dioxide, methane, and organic vapors) provides key information about existing biological activity before system startup. Depleted oxygen concentrations suggest that microbial activity, and hence hydrocarbon biodegradation, may be oxygen limited. Because aerobic activity produces carbon dioxide, higher carbon dioxide concentrations are often observed in areas where there is or has been significant aerobic activity. The presence of methane and carbon dioxide could suggest anaerobic biological activity or the migration of landfill gas from the landfill to the bioventing target area (discussed later). The amount of organic vapors can indicate the amount of hydrocarbons present in the soil.

Before startup, each air injection well (AW-1 through AW-29) and each soil gas probe (GM-01 through GM-06) were purged with a vacuum pump, and a soil gas sample was analyzed for oxygen, carbon dioxide, methane, and organic vapors. Soil gases were measured with a GasTech Infra-Red Gas Analyzer. The results of the initial analyses are shown on Table 4-1.

Based on an interpretation of the soil gas results, it appears that the bioventing target area can be divided into three sub-areas (Figure 4-1). Area A is the target zone north and east

Table 4-1 Initial Soil Gas Analyses				
Well	O_2 (%)	CO_2 (%)	Methane (%)	% LEL
AW-01	16.5	3.5	0.2	4
AW-02	9.0	6.9	0.1	2
AW-03	10.3	6.5	0.2	4
AW-04	13.9	2.9	0.4	8
AW-05	11.0	4.6	0.1	2
AW-06	15.4	5.1	0.2	4
AW-07	19.1	0.5	0.3	6
AW-08	15.4	4.4	0.1	2
AW-09	18.0	2.6	0.2	4
AW-10	19.0	0.8	0.0	0
AW-11	15.0	2.4	0.3	6
AW-12	16.0	2.5	0.1	0
AW-13	12.2	4.6	0.0	0
AW-14	2.2	7.3	2.2	54
AW-15	3.3	4.7	4.9	98
AW-16	11.5	5.3	0.9	14
AW-17	0.7	9.7	3.5	68
AW-18	11.0	0.2	8.8	1
AW-19	10.8	5.7	0.7	6
AW-20	4.8	10.2	0.2	1
AW-21	1.1	13.1	0.8	12
AW-22	2.0	11.6	29.0	100
AW-23	17.9	2.8	0.1	4
AW-24	0.7	11.0	1.7	12
AW-25	7.1	9.3	0.0	0
AW-26	11.3	7.6	0.0	0
AW-27	4.8	9.0	0.1	2
AW-28	17.6	1.9	0.0	0
AW-29	18.8	1.5	0.0	0
GM-01-S	15.9	4.9	0.3	6
GM-01-D	16.2	4.9	0.3	6
GM-02-S	10.6	6.2	0.2	4
GM-02-D	6.7	6.4	0.2	4
GM-03-S	8.1	9.2	0.1	2
GM-03-D	15.2	5.2	0.1	2
GM-04-S	0.2	17.6	1.1	22
GM-04-D	0.6	17.9	13.4	286
GM-05-S	0.7	17.5	0.3	4
GM-05-D	0.3	14.8	0.9	18
GM-06-S	17.7	2.3	0.0	0
GM-06-D	17.4	2.3	0.0	0

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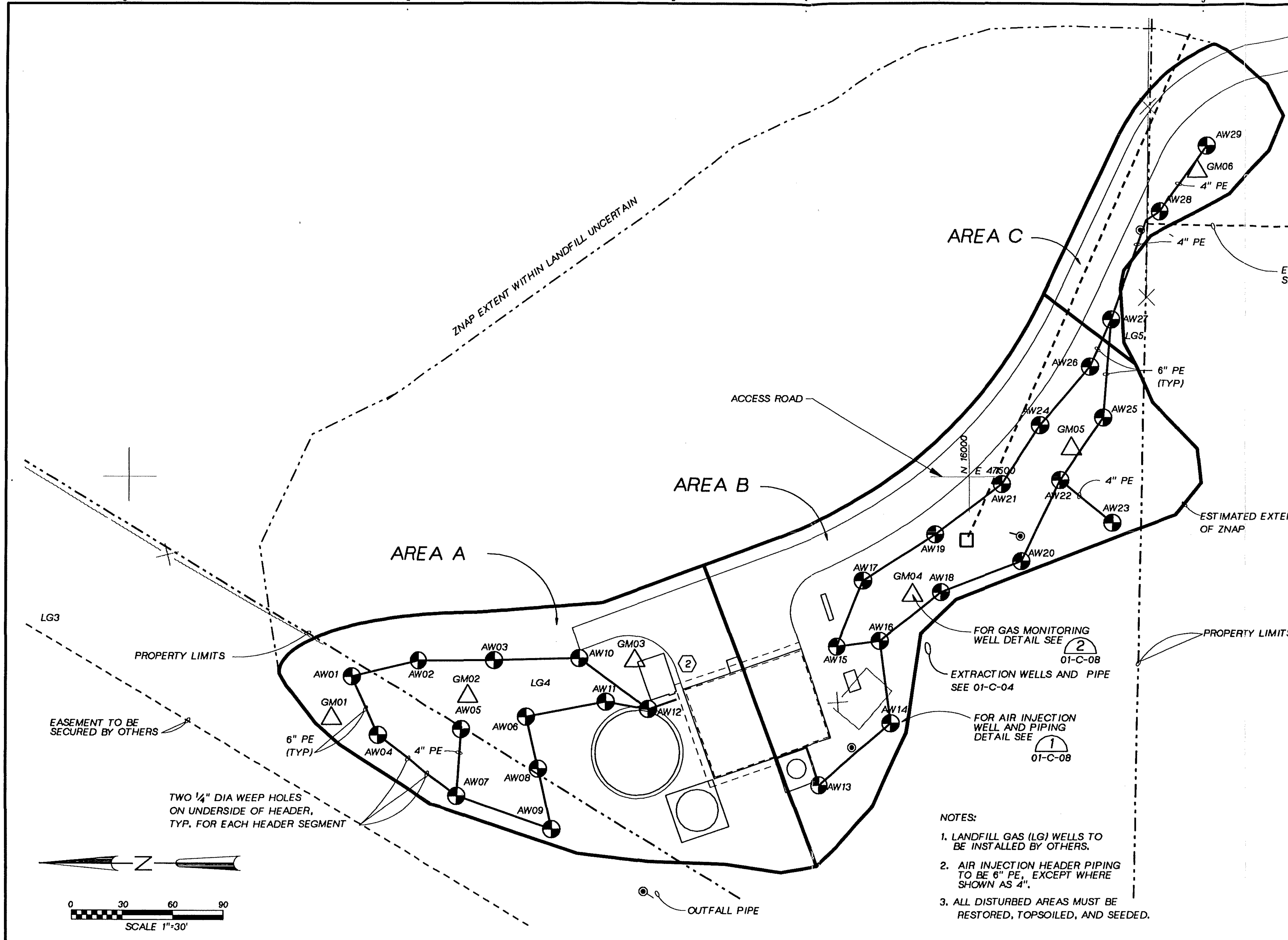

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GM01	16379	47357
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GROUNDWATER REMEDIAL ACTION

ONALASKA MUNICIPAL LANDFILL SITE
ONALASKA TOWNSHIP, WISCONSIN

Figure 4-1
Bioventing Target Sub-Areas

of the clarifier. It is characterized by low but not depleted oxygen concentrations. Oxygen concentrations in this area ranged from 9 to 19.1 percent. Carbon dioxide concentrations were elevated, but were less than 7 percent. Methane was not detected above 1 percent. Based on this data and the site investigation data, these soils appear affected by hydrocarbons, but appear generally less contaminated than other soil. There appears to be ongoing microbial activity, and the activity may not be limited by the availability of oxygen in the soil gas.

Area B is the area south of the treatment building and north of AW-26 (Figure 4-1). Oxygen was significantly depleted in this area, with many oxygen measurements less than 2 percent. The carbon dioxide concentrations ranged up to 17.5 percent. Microbial activity in this area appeared to be limited by the low levels of oxygen. Methane ranged up to 29 percent (see AW-22). However, almost all other methane concentrations were less than 5 percent, suggesting that the 29 percent concentration is an anomaly, possibly caused by the localized migration of landfill gas around AW-22. Free product was observed in AW-22. Before startup, all air injection wells were sampled for free product. AW-22 was the only well with free product, having about 1/16 of an inch. Based on this data and site investigation data, Area B appears to be the most contaminated area within the bioventing target zone.

Area C is the southeastern portion of the treatment zone, extending from AW-26 to AW-29. Its soil gas parameters and degree of hydrocarbon contamination appear similar to that of Area A. Whereas some oxygen depletion was observed, there appeared to be sufficient oxygen to sustain microbial activity.

Table 4-2 presents a summary of the soil gas parameters for each area.

Air Injection Flow Rates

On May 24, the air injection blower was started up and the flow rate into each well was measured with the flow valves fully open. The resulting flow rates to each well are shown in Table 4-3. Varying flow rates were observed between each well, and no flow was observed in AW-8, -14, -15, and -23. These wells may be in localized areas of less permeable soil that are more resistant to air flow. Based on soil gas pressure readings (discussed below) and ongoing soil gas composition analyses, it appeared that Area A required less flow to maintain sufficient oxygen levels. Thus overall flows were reduced in Area A and increased in Areas B and C by turning off AW-1, 2, 3, 6, 7, 9, and 10. Total system flow has been maintained between 280 to 300 scfm. Given the soil pore volume in the bioventing target area, this correlates to 1.3 pore volume exchanges per day. As discussed below, this flow easily maintains aerobic conditions in almost the entire target area.

Table 4-2 Summary of Soil Gas Composition Prestartup Sampling			
Area	**Oxygen (%)**	**CO_2 (%)**	**Methane (%)**
A	9.0–19.1	0.8–6.9	0–0.4
B	0.3–17.9	2.8–17.9	0–29
C	4.8–18.9	1.5–9.0	0–6

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Table 4-3 Summary of Flow to Air Injection Wells						
Air Injection Well	**Flow (scfm) 24-May**	**Flow (scfm) 2-Jun**	**Flow (scfm) 16-Jun**	**Flow (scfm) 11-Jul**	**Flow (scfm) 26-Jul**	**Flow (scfm) 1-Aug**
AW-1	19	0	0	0	0	0
AW-2	15	0	0	0	0	0
AW-3	12	0	0	0	0	0
AW-4	12	25	25	17	24	25
AW-5	20	35	35	39	36	36
AW-6	10	0	0	0	0	0
AW-7	24	0	0	0	0	0
AW-8	0	0	0	0	0	0
AW-9	16	0	0	0	0	0
AW-10	16	0	0	0	0	0
AW-11	11	28	28	22	27	27
AW-12	13	25	25	23	26	25
AW-13	5	13	13	9	11	14
AW-14	0	0	0	0	1	1
AW-15	0	0	0	3	1	1
AW-16	1	1	1	4	1	1
AW-17	11	16	16	18	16	16
AW-18	1	4	4	2	4	4
AW-19	13	12	12	14	12	12
AW-20	12	16	16	21	19	19
AW-21	17	12	12	14	13	12
AW-22	3	9	9	4	8	8
AW-23	0	0	0	0	0	0
AW-24	7	13	13	11	12	13
AW-25	10	15	15	15	15	15
AW-26	12	18	18	19	17	18
AW-27	9	17	17	15	16	17
AW-28	9	17	17	18	16	16
AW-29	20	10	10	21	20	19
Total Flow	299	286	286	289	293	295

Air Injection Well Influence

The air injection wells were placed about 40 to 50 feet apart. Based on estimates of the soil air permeability, it was predicted during the design that this spacing would result in the entire target zone being aerated. The movement of air flow through the target zone is assessed through two methods. The first of these methods is performed by measuring the pressure in the soil gas probes. As the air is injected into the soil, a resulting pressure field is set up around each air injection well. The radial extent of the pressure field indicates the distance to which the injected air is reaching. Soil gas pressures were measured at each soil gas probe with a Dwyer Magnehelic Gauge. Whereas a single pressure measurement cannot be used to assess gas flow direction and velocity, it can confirm that the location of sampling is generally within the influence of an air injection well. The results of pressure readings in the soil gas probes are shown in Table 4-4.

Average pressures ranged from 0.09 to 0.70 inches of water, which is about 10 percent of the pressure in the air injection wells. The propagation of pressure through the vadose zone soil suggests little resistance to air flow and high air permeability. The deeper soil gas probes tend to have higher pressures than the shallow soil gas probes, suggesting that the air flow is largely moving as intended through the lower portion of the vadose zone (e.g., smear zone), and not short circuiting to the ground surface.

The second method of assessing soil gas movement is through changes in soil gas composition during bioventing. As air is injected into the target zone, the composition of the soil gas eventually approaches atmospheric conditions (i.e., 21 percent oxygen and 0.1 percent carbon dioxide). Table 4-5 shows changes in soil gas composition at each of the monitoring probes since the start of bioventing. Figure 4-2 is a graph of oxygen changes in each of the shallow soil gas probes since startup, and Figure 4-3 shows average oxygen and carbon dioxide changes for all the soil gas probes.

In all cases except at one monitoring probe, bioventing resulted in oxygen concentrations increasing to above 14 percent, and in most cases oxygen concentrations increased to almost 20 percent. Gas probes in Area A (GM-01, GM-02, and GM-03) as well as the gas probe in Area C (GM-06) have relatively high oxygen concentrations. Gas probes in Area B (especially GM-04) have lower oxygen concentrations, suggesting more oxygen demand. The oxygen concentration in GM-04D has increased from 0.6 percent at the start of bioventing to only 3.2 percent, and the oxygen concentration in GM-04S has increased from 0.2 to 14.4 percent.

As shown in Figure 4-3, average carbon dioxide concentrations have decreased from 10 percent to about 2 percent, and average oxygen concentrations have increased from 9.1 to 17.8 percent. Since there is an ongoing uptake of oxygen and production of carbon dioxide, the system soil gas concentrations will never fully reach atmospheric conditions for air. Yet these data do show the general effectiveness of the system in aerating the soil.

Table 4-4 Summary of Startup Soil Gas Pressures								
Probe	**24-May**	**25-May**	**2-Jun**	**16-Jun**	**11-Jul**	**26-Jul**	**1-Aug**	**Average**
GM-01-S	0.16	0.08	0.07	0.08	0.08	0.08	0.08	0.09
GM-01-D	0.16	0.08	0.08	0.08	0.08	0.07	0.08	0.09
GM-02-S	0.40	0.29	0.27	0.21	0.26	0.22	0.21	0.27
GM-02-D	0.45	0.38	0.37	0.28	0.36	0.27	0.28	0.34
GM-03-S	0.20	0.20	0.20	0.20	0.32	0.22	0.25	0.23
GM-03-D	0.48	0.44	0.41	0.46	0.70	0.51	0.48	0.50
GM-04-S	0.33	0.30	0.28	0.32	0.45	0.35	0.30	0.33
GM-04-D	0.58	0.64	0.60	0.66	0.92	0.74	0.75	0.70
GM-05-S	0.40	0.46	0.40	0.47	0.92	0.47	0.45	0.51
GM-05-D	0.58	0.64	0.60	0.62	0.94	0.70	0.66	0.68
GM-06-S	0.14	0.17	0.16	0.14	0.20	0.12	0.12	0.15
GM-06-D	0.15	0.17	0.16	0.15	0.25	0.13	0.13	0.16
Units in inches of water.								

Table 4-5
Results of Soil Gas Analysis During Bioventing Startup

Probe	Oxygen 18-May	CO2 18-May	Methane 18-May	Oxygen 25-May	CO2 25-May	Methane 25-May	Oxygen 2-Jun	CO2 2-Jun	Methane 2-Jun	Oxygen 16-Jun	CO2 16-Jun	Methane 16-Jun	Oxygen 23-Aug	CO2 23-Aug	Methane 23-Aug
GM-01-S	15.9	4.9	0.3	16.1	1.2	0.3	16.1	5.2	0.4	17.5	3.2	0.4	18.5	1.4	0.0
GM-01-D	16.2	4.9	0.3	15.9	5.6	0.3	18.1	4.5	0.2	18.4	1.7	0.4	16.8	2.3	0.0
GM-02-S	10.6	6.2	0.2	21.0	1.0	0.0	21.0	0.5	0.4	20.8	0.0	0.7	20.4	0.0	0.0
GM-02-D	6.7	6.4	0.2	20.9	0.6	0.5	20.8	0.5	1.6	20.4	0.3	4.3	20.3	0.2	0.2
GM-03-S	8.1	9.2	0.1	19.2	6.4	0.2	19.6	5.2	0.2	19.5	2.4	0.3	18.4	2.0	0.0
GM-03-D	15.2	5.7	0.1	21.0	0.1	0.2	21.0	0.0	0.2	20.8	0.0	0.6	20.4	0.0	0.0
GM-04-S	0.2	17.6	1.1	0.5	17.9	1.9	2.5	17.4	8.4	0.3	19.4	0.6	14.4	5.2	0.0
GM-04-D	0.6	17.9	13.4	1.1	19.1	7.6	1.5	17.8	1.9	0.7	20.6	7.6	3.2	11.3	1.5
GM-05-S	0.7	17.5	0.3	17.0	8.0	0.3	17.3	7.6	0.3	19.3	3.2	0.1	20.1	0.4	0.0
GM-05-D	0.3	14.8	0.9	20.9	0.4	0.2	21.0	0.2	0.2	21.0	0.0	0.2	20.5	0.0	0.0
GM-06-S	17.7	2.3	0.0	21.0	0.0	0.2	21.0	0.0	0.2	20.9	0.0	0.2	20.5	0.0	0.0
GM-06-D	17.4	2.3	0.0	21.0	0.0	0.2	21.0	0.0	0.2	20.9	0.0	0.2	20.5	0.0	0.0
Average	9.1	9.1	1.4	16.3	5.0	1.0	16.7	4.9	1.2	16.7	4.2	1.3	17.8	1.9	0.1

Note: All readings in percent of total gas by volume.

Figure 4-2
Change in Oxygen Concentrations with Air Injection

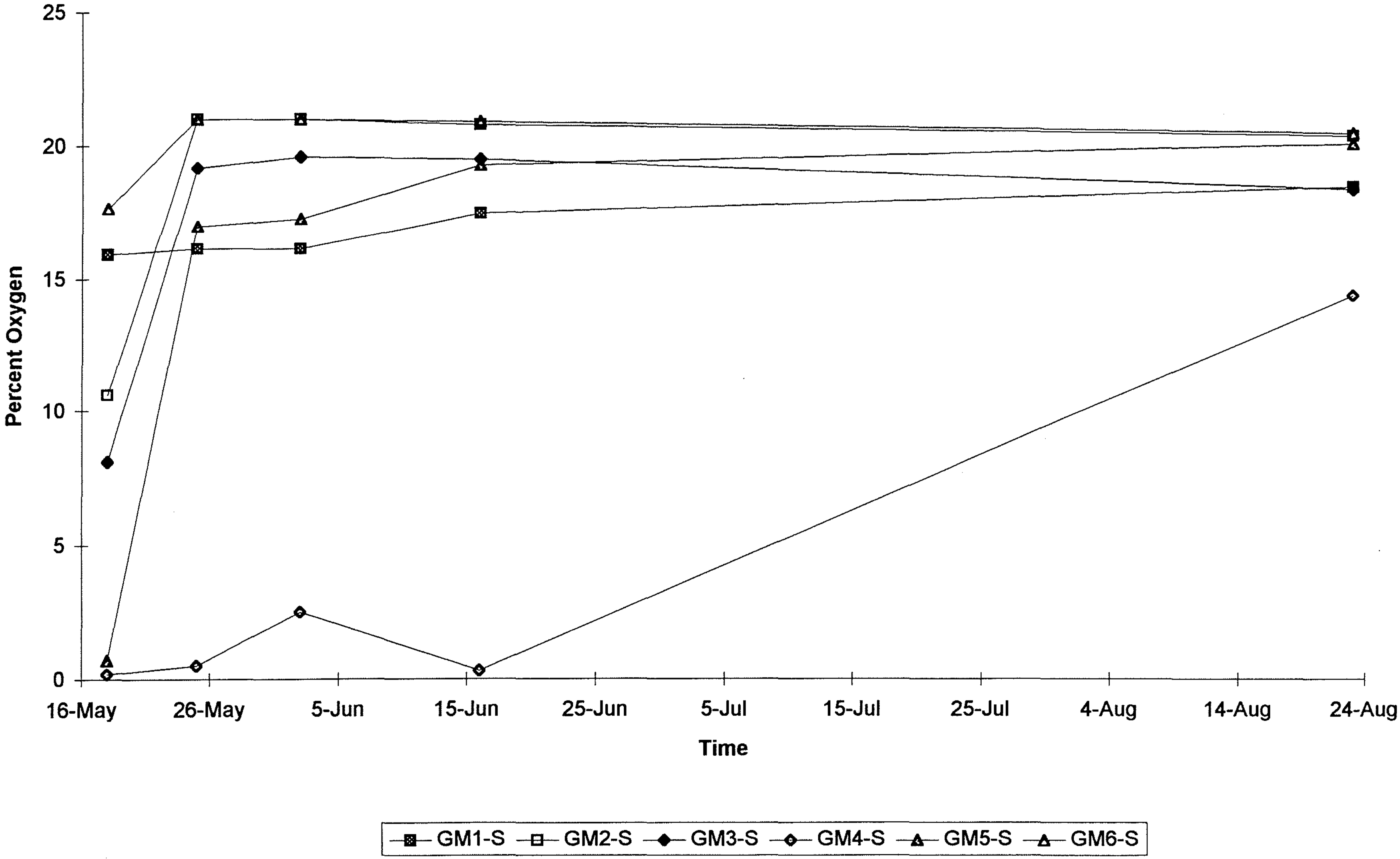

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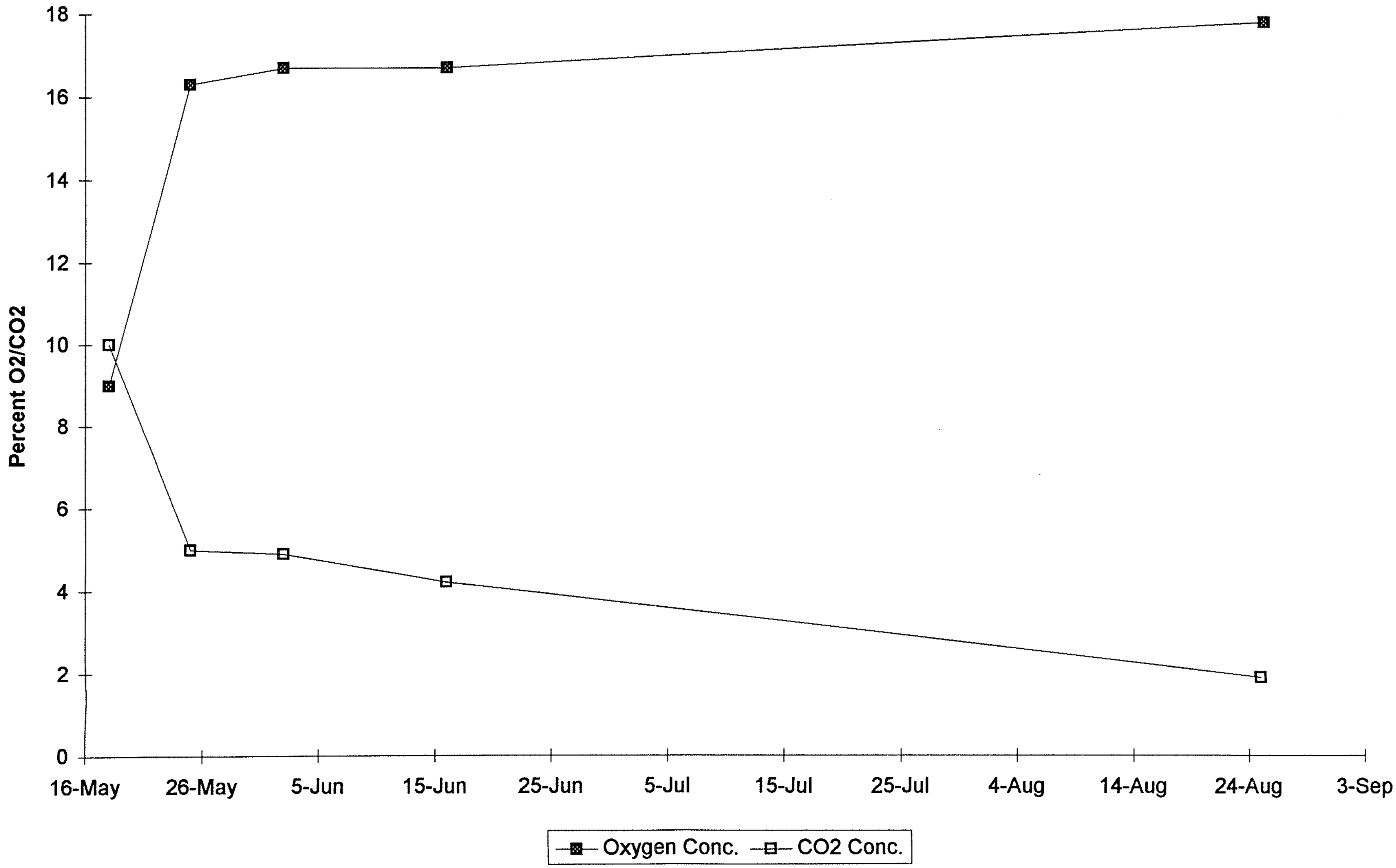
Figure 4-3
Change in Average Oxgyen and CO2 Concentrations in Soil Gas



Changes in methane concentrations listed in Table 4-5 show that methane concentrations have continuously decreased. Average methane concentrations decreased from 1.4 percent in May to 0.1 percent in August. This suggests that no further landfill gas is migrating into the treatment zone.

Soil Respiration Study

The overall objective of aerating the target zone soil is to increase the rate of hydrocarbon biodegradation. An assessment of the hydrocarbon biodegradation rate can be made from the stoichiometry of hexane mineralization (hexane is a common petroleum hydrocarbon). If hexane is completely biodegraded, it is mineralized to carbon dioxide and water as shown in the following equation:

$$C_6H_6 + 7.5\ O2 \rightarrow 6\ CO_2 + 3\ H_2O$$

When this stoichiometric relationship is converted to a mass relationship, each pound of hydrocarbon (hexane) that is biodegraded requires 3.5 pounds of oxygen. The objective of the soil respiration study is to assess the rate of oxygen uptake and correlate that rate to an equivalent amount of hydrocarbon biodegradation.

On August 24 and 25, a 48-hour oxygen uptake study was undertaken in which the air injection system was shut down and the rate of oxygen uptake was measured in the shallow and deep piezometers at GM-01, GM-02, GM-03, GM-04, and GM-05. Uptake studies were also performed at AW-17 and AW-19. The resulting oxygen decreases are shown in Table 4-6 and graphically in Figure 4-4 for Area A and Figure 4-5 for Area B.

In Area A there was an average oxygen decrease of 1.5 percent per day. Based on the stoichiometric relationship discussed above, this is equivalent to an approximate 1 mg/kg/day hydrocarbon biodegradation rate. Typical rates of hydrocarbon degradation range from 0.5 to 15 mg/kg/day. Thus the rate observed in Area A is within but toward the lower end of hydrocarbon biodegradation rates typically observed in soil. Given the mass of soil in Area A, about 40 pounds of hydrocarbons are being biodegraded per day if all of the oxygen uptake is related to hydrocarbon biodegradation.

In Area B, the average oxygen decrease was 3 percent per day. This is equivalent to an approximate biodegradation rate of 2 mg/kg/day, which is toward the lower end of what is typical for hydrocarbon biodegradation. Given the mass of soil in Area B, about 125 pounds of hydrocarbons are biodegraded per day if all of the oxygen uptake is associated with hydrocarbon biodegradation.

No direct measurement of oxygen uptake was made in Area C, but given other conditions observed in Area C, it is likely that the oxygen uptake rate is similar to that for Area A. Given the small mass of soil in Area C, the amount of hydrocarbon biodegradation is not more than a few pounds of hydrocarbons per day.

Table 4-6
Summary of Soil Respiration Study

	GM1-S	GM1-D	GM2-S	GM2-D	GM3-S	GM3-D	GM4-S	GM5-S	GM5-D	AW-17	AW-19
Area	**A**	**A**	**A**	**A**	**A**	**A**	**B**	**B**	**B**	**B**	**B**
Time (hours)	**%O2**	**%O2**	**%O2**	**%O2**	**%O2**	**%O2**	**%O2**	**%O2**	**%O2**	**%O2**	**%O2**
0	18.5	16.8	20.4	20.3	18.4	20.4	14.4	20.1	20.5	20.5	20.5
2	18.3	17.1	20.3	19.9	17.6	19.8	13.8	19.8	20.2	19.9	20.1
6	17.8	16.4	19.9	19.2	15.6	19.3	13.2	19.0	19.5	19.6	19.9
9	17.9	16.2	19.9	19.2	16.2	19.4	13.3	18.6	19.1	19.7	20.2
24	17.5	14.9	19.7	18.1	14.5	18.5	12.9	17.6	17.3	17.6	19.1
48	16.3	12.8	19.0	15.7	12.0	15.8	11.8	16.1	11.2	12.2	10.9
Total O2 Change	2.2	4.0	1.4	4.6	6.4	4.6	2.6	4.0	9.3	8.3	9.6
02 Change/Day	1.1	2.0	0.7	2.3	3.2	2.3	1.3	2.0	4.7	4.2	4.8

Figure 4-4
Oxygen Uptake in Area A

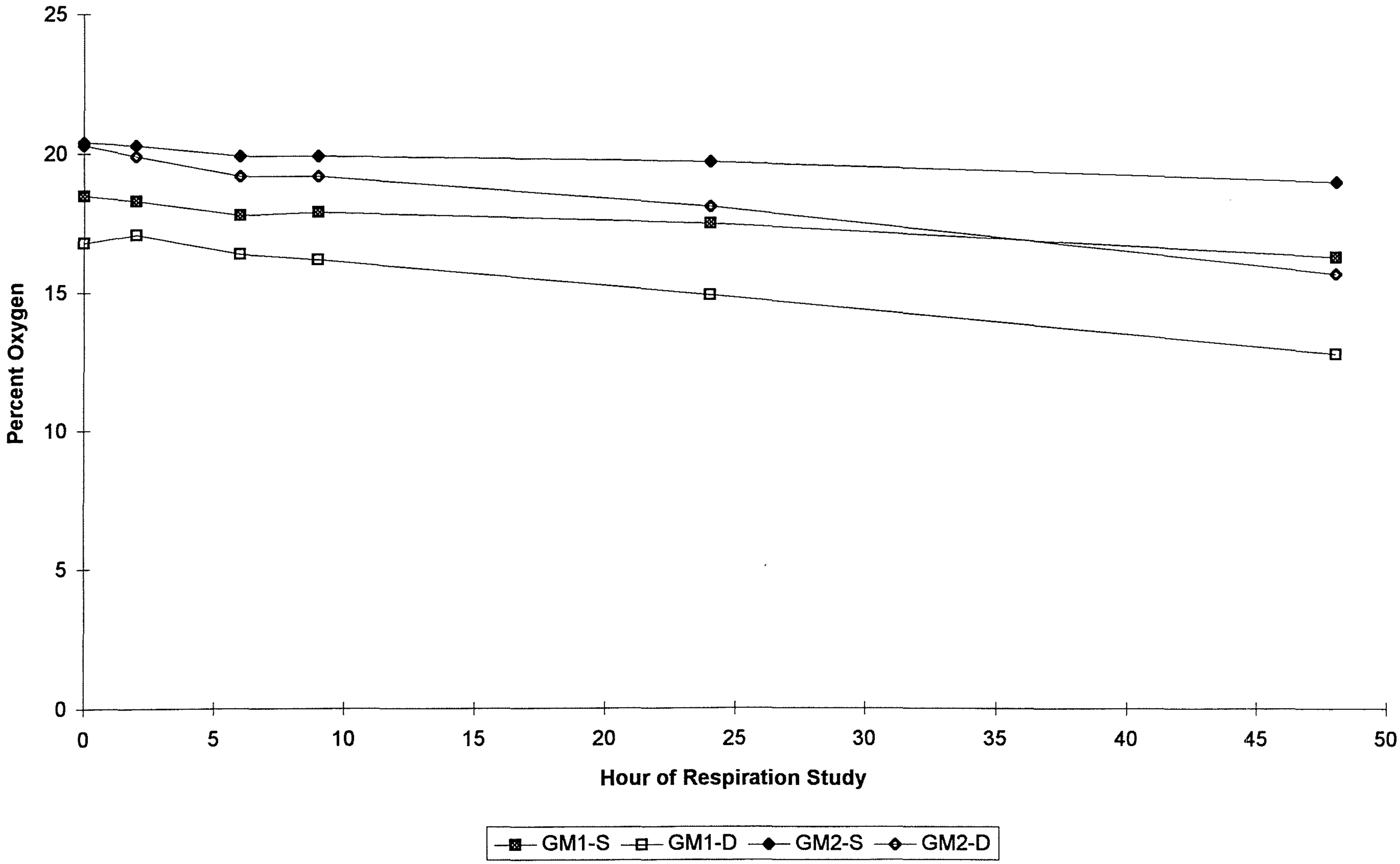
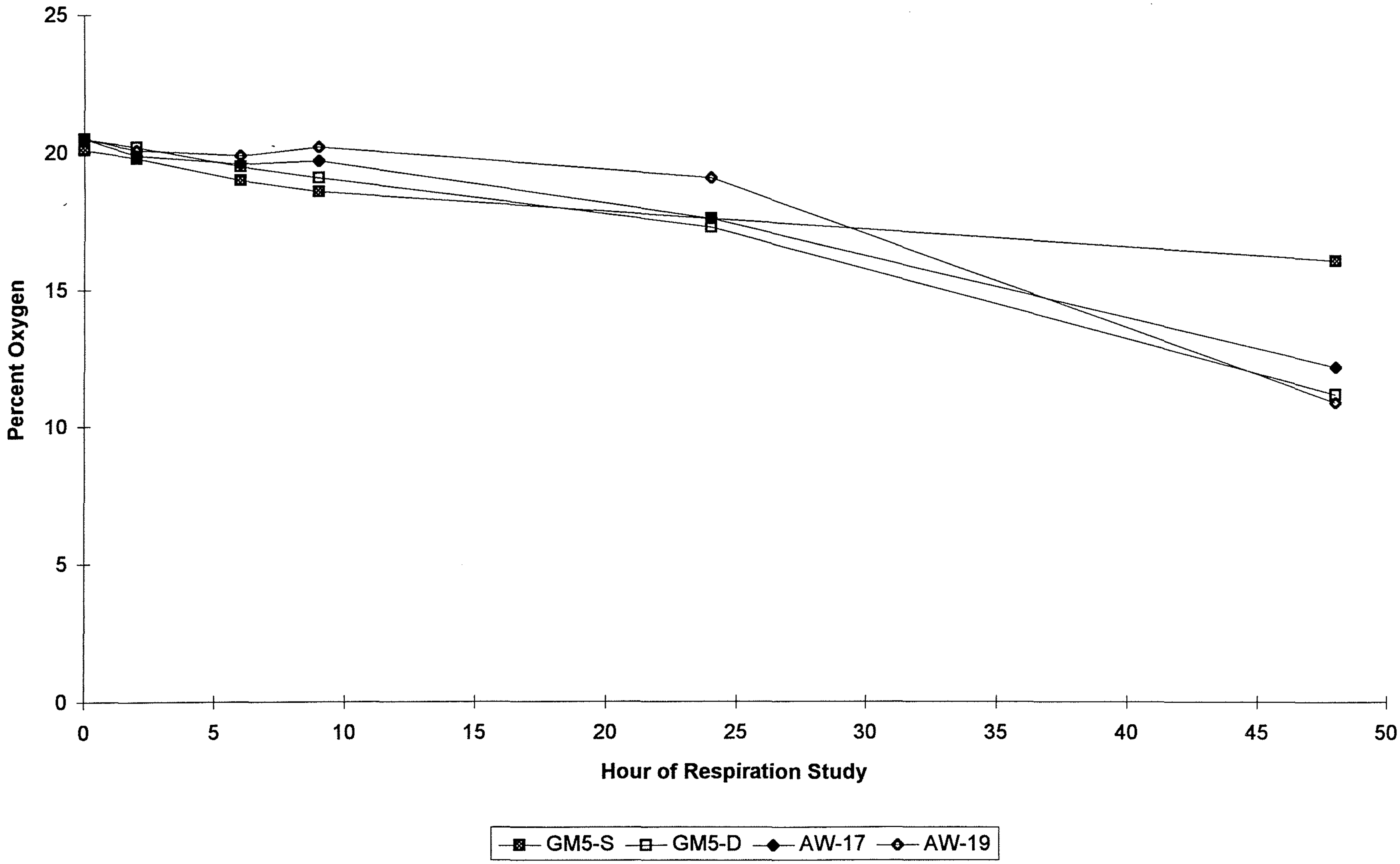


Figure 4-5
Oxygen Uptake in Area B



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Oxygen uptake studies were also done on the soil columns during the in situ bioventing laboratory study. The results of these studies showed oxygen uptake rates 3 to 5 times greater than those observed in the field. One reason for the difference may be that the soils collected for the laboratory study were from the most contaminated portion of the site. These heavily contaminated soils may have resulted in more microbial uptake than the average soil for the site. It is also possible that current actual oxygen uptake rates are greater than those observed during the field respiration study, but that ongoing diffusion of oxygen through the soil surface supplies more oxygen and so masks the actual rate of oxygen uptake in soil. In this case, the hydrocarbon biodegradation rates discussed above would be lower than what is actually occurring and the rate of hydrocarbon biodegradation would be underestimated.

Conclusions

The data collected to date indicate that the bioventing system is operating as designed. While the resulting hydrocarbon degradation rates are not high, they will still result in a large mass of hydrocarbon biodegradation over the next 2 to 3 years. As seasonal water table fluctuations raise and lower the water table, more hydrocarbons may also become exposed to the influence of the bioventing system. Assuming an existing average hydrocarbon concentration of 2,000 mg/kg and a hydrocarbon biodegradation rate of 2 mg/kg/day, the time to achieve removal for most hydrocarbons is estimated to be 1,000 days or 2.7 years.

Anticipated work during the next 2 months includes:

- Further adjustment of flow so that more air is injected into Area B.
- One more oxygen uptake study in October. This study will last for at least 5 days to assess whether all the available oxygen will be eventually depleted.
- Ongoing measurements of system flows and pressures.

Further reports will be submitted to the U.S. EPA at the end of this year.

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