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Site 5 air sparging pilot test, Naval Air Station Cecil Field, Jacksonville, Florida

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Abstract

A 72-h air sparging pilot test was conducted at Site 5 (Operable Unit 2), Naval Air Station Cecil Field, Jacksonville, FL, to determine performance parameters necessary for full-scale design. The sparge well was completed to a depth of 29 ft, several feet below the groundwater plume contaminated with volatile organic compounds (VOCs), primarily benzene, toluene, ethylbenzene, and xylenes (BTEX). Air flow rates supplied to the sparge well were 3 cubic feet/min (cfm) during the first day, 2 cfm during the second day, and 1 cfm during the third day. Water levels in monitoring wells initially rose approximately 2 ft during the first 4–5 h of the test, then receded back to pre-test equilibrium levels over the next 15 h, for a total duration of water mounding of about 20 h. A small (approximately 0.5 ft) water table drop, with subsequent recovery to equilibrium level, occurred each time the air sparging rate was decreased. Although there is considerable variation depending on direction from the sparge well, the average radius of influence varied from approximately 30 ft at 1 cfm to 50 ft at 3 cfm. The air sparge system was capable of increasing the dissolved oxygen from 0 to 6 or 7 mg/l within 12–15 h of air channels reaching a given location. A lag time of approximately 13 h was observed before air channels reached a radius of 30 ft and dissolved oxygen levels began to increase at that radius. CO_2 (stripped out of the groundwater by the sparging) decreased from a pre-test concentration of 150 to 20 mg/l at $r = 5$ ft, and from 150 to 50 mg/l at $r = 30$ ft, within a period of about 24 h. The rate of VOC mass removal during the pilot test was 0.06 lb/day at a sparge rate of 3 cfm, and it appears that air sparging will effect a rapid cleanup of the VOCs in the Site 5 groundwater plume.

Keywords: Groundwater; Air sparging; Pilot test; Radius of influence; VOCs

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1. Introduction

The Record of Decision (ROD) [1] for Site 5 (Operable Unit [OU] 2) at Naval Air Station (NAS) Cecil Field, Jacksonville, FL, specifies that an air sparging pilot test should be conducted, and, if found effective, air sparging will be implemented as the selected remedy for groundwater cleanup. This report describes the air sparging pilot test which was conducted at Site 5 to satisfy the following objectives.

- Determine the performance of air sparging by locating the sparge well in the middle of the groundwater plume where concentrations of volatile organic compounds (VOCs) are the highest.
- Conduct the pilot test without the vapor extraction system, but measure concentrations of VOCs in the sparged air emissions to determine the need for, and sizing of, a vapor collection and treatment system.
- Determine optimum operating parameters such as air flow rate, system air pressures, and radius or area of influence.
- Interpret pilot test results to provide input for full-scale design and cost estimates.

In Sections 2–4, first the site background is summarized; then the pilot test setup, test execution, and results of data collection are described. Finally, a summary and conclusions are presented.

2. Site background

Site 5 is located at NAS Cecil Field in Jacksonville, Duval County, FL (Figs. 1 and 2), and was reportedly used for the disposal of mixed oil, sludge, spent solvents, and grease wastes in an unlined shallow pit or trench. The soils and shallow surficial aquifer are composed of silty sands (see Fig. 3).

Remedial Investigation and Feasibility Study activities were conducted by Harding Lawson Associates (formerly ABB Environmental Services) [2,3] from 1990 through 1995. An Interim Remedial Action (IRA) was executed in 1995 and 1996 to address soil contamination and free product at the site. Approximately 6200 $yard^3$ of soil (0–2 ft below land surface [bls] over the site area, and overexcavation to beneath the groundwater table in the area of known free product contamination) were excavated and treated on site.

The extent of groundwater contamination is shown on Figs. 4 and 5 for VOCs and semivolatile organic compounds (SVOCs), respectively. Groundwater contamination is confined to the shallow groundwater (no more than 20 ft bls), and appears to be migrating slowly toward the drainage ditch south of the site. The estimated volume of contaminated groundwater, based on both VOCs and SVOCs, is 2.1 million gal. This calculation assumes a contaminated water column of 20 ft and a soil porosity of 0.35. The mass of total VOCs in groundwater is 6 kg (13.2 lb), and the mass of total SVOCs is 8 kg (17.6 lb).

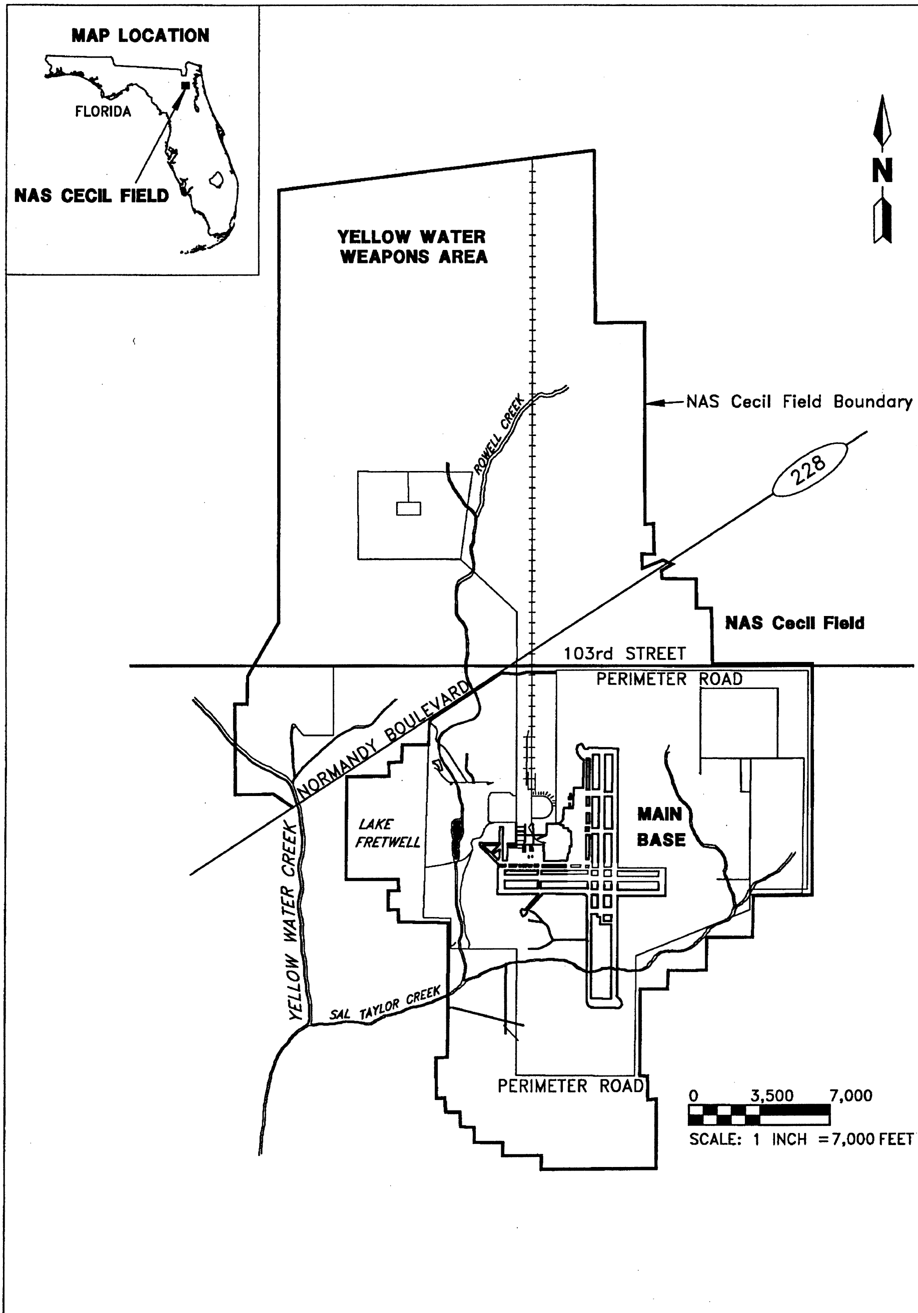

Fig. 1. General location map.

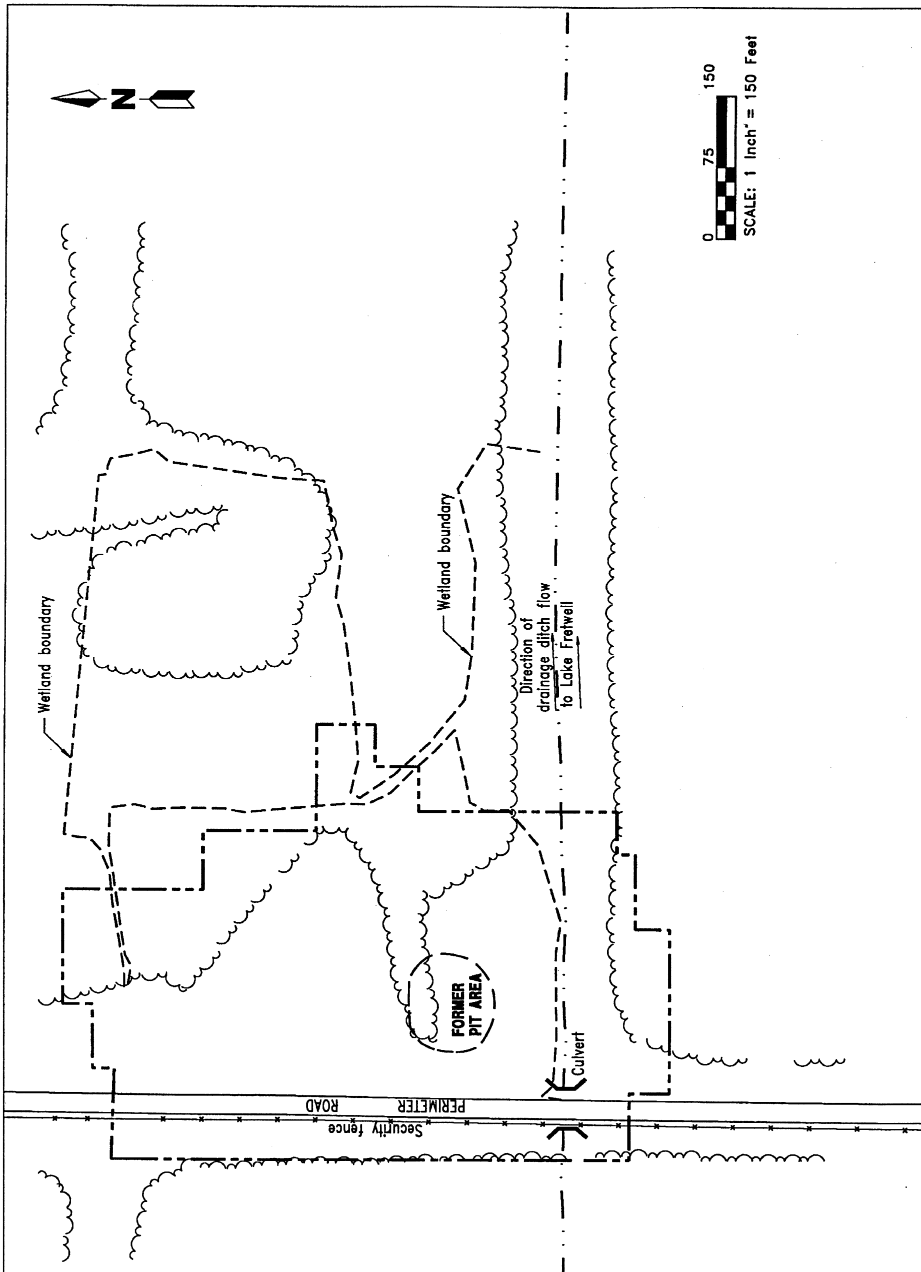

Fig. 2. General features.

3. Test setup

Rainfall in the weeks prior to testing left standing water over most of the area where 2 ft of surface soil had been excavated at the site. This made access for well installation impossible using conventional equipment. Therefore, on June 4 and 5, 1997, prior to well installation, a road was constructed into the site. Soil that had been previously thermally treated and stockpiled at Site 5 was used to construct the road. The road was approximately 15 ft wide and 2 ft deep (bringing the road surface to original grade) and ran east from Perimeter Road into the test site area shown on Fig. 6.

On June 6, 7, and 8, 1997, after the access road was constructed, nine small diameter wells were installed through the access road using direct push technology. Each well had either a 3- or 6-foot long, 0.5-in. diameter polyvinyl chloride (PVC) screen (0.01 in. slot size) within a 1.5-in. diameter stainless steel prepacked screen. Riser pipe was 0.5-in.

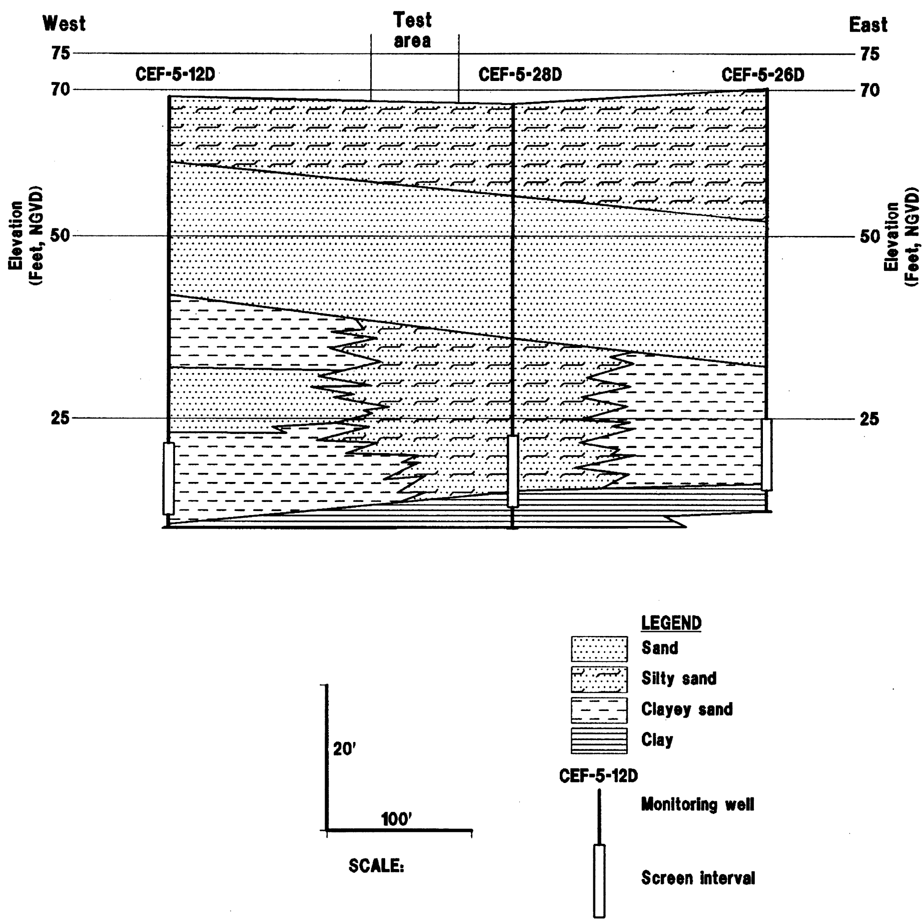

Fig. 3. Geologic cross-section.

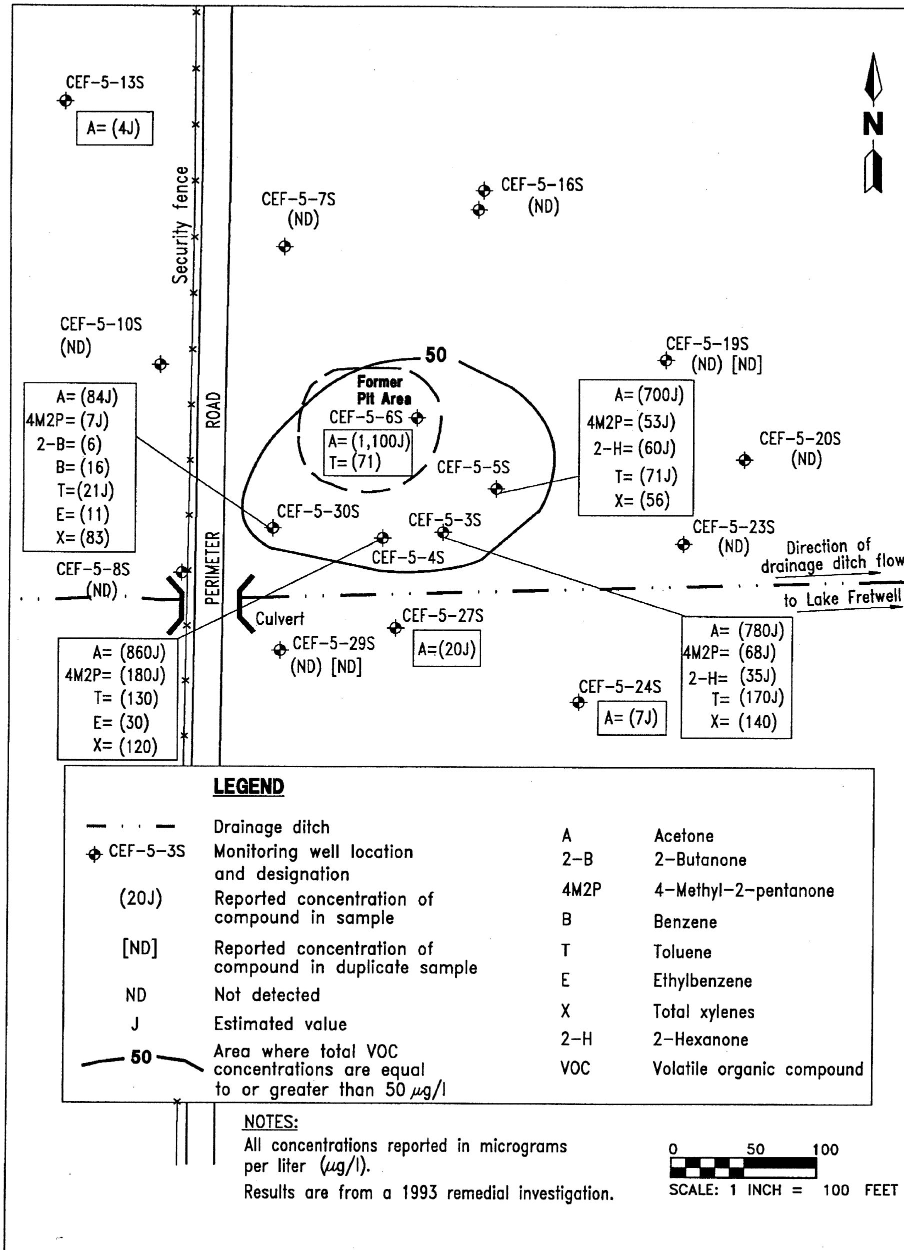

Fig. 4. VOCs in groundwater, upper surficial aquifer.

diameter Schedule 80 PVC. The air sparge well (AS-1) was screened from 26 to 29 ft bls. Four groundwater monitoring point (GMP) wells were installed at distances of 5, 10,

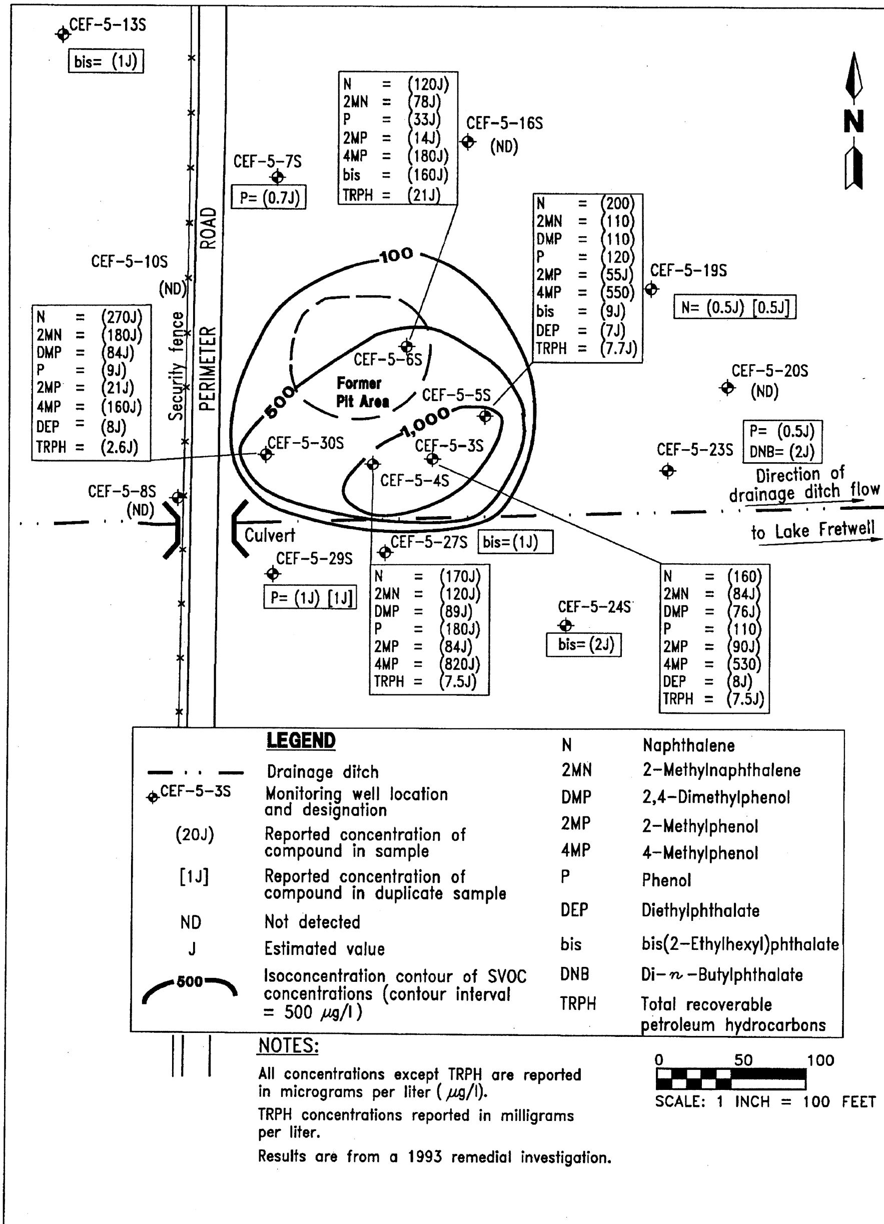

Fig. 5. Semivolatile VOCs (SVOCs) and total recoverable petroleum hydrocarbons (TRPH) in groundwater, upper surficial wells.

20, and 30 ft to the east from AS-1, and were screened from 12 to 15 ft bls. GMP wells were used to collect groundwater samples for laboratory analyses of contaminants and

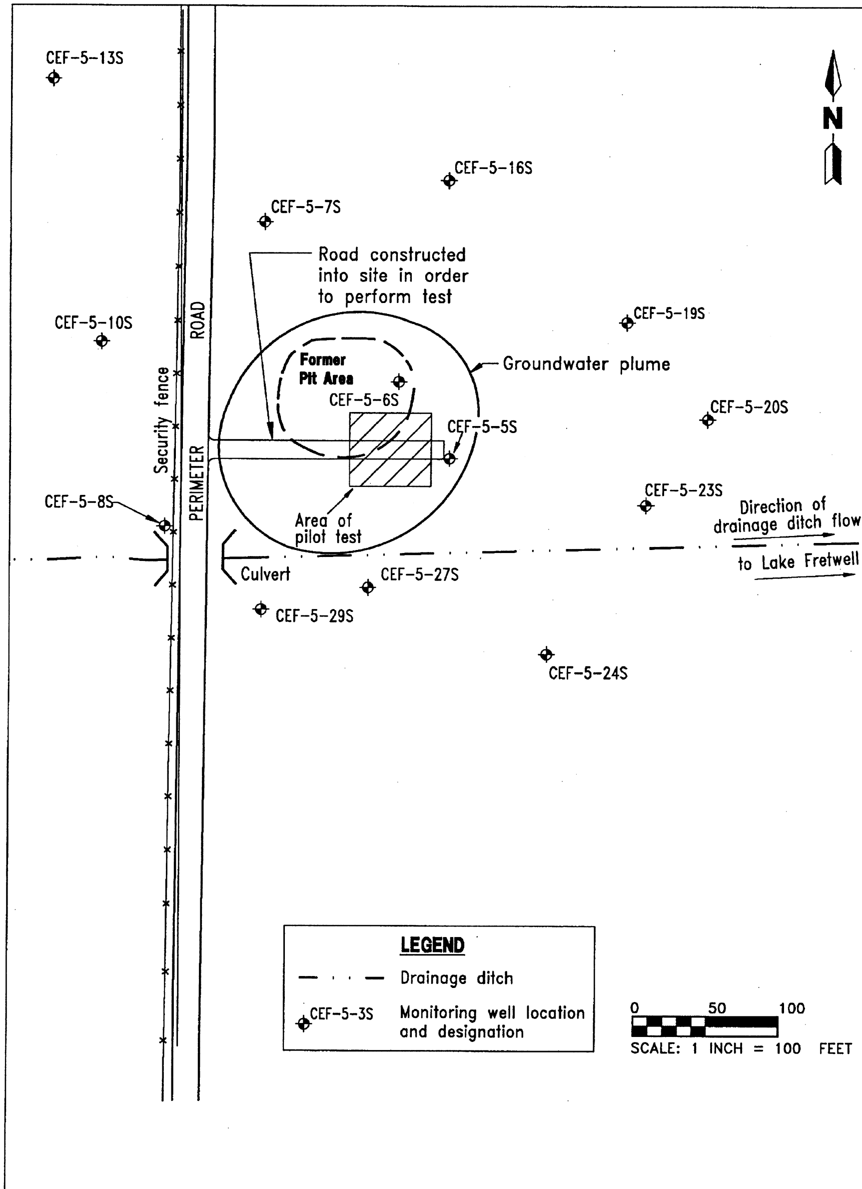

Fig. 6. Location of pilot test.

field analyses of dissolved oxygen and carbon dioxide. Four vapor monitoring point (VMP) wells were installed at distances of 5, 10, 15, and 25 ft to the west from AS-1, and were screened from 3 to 9 ft bls. VMP wells were used to collect water-level data

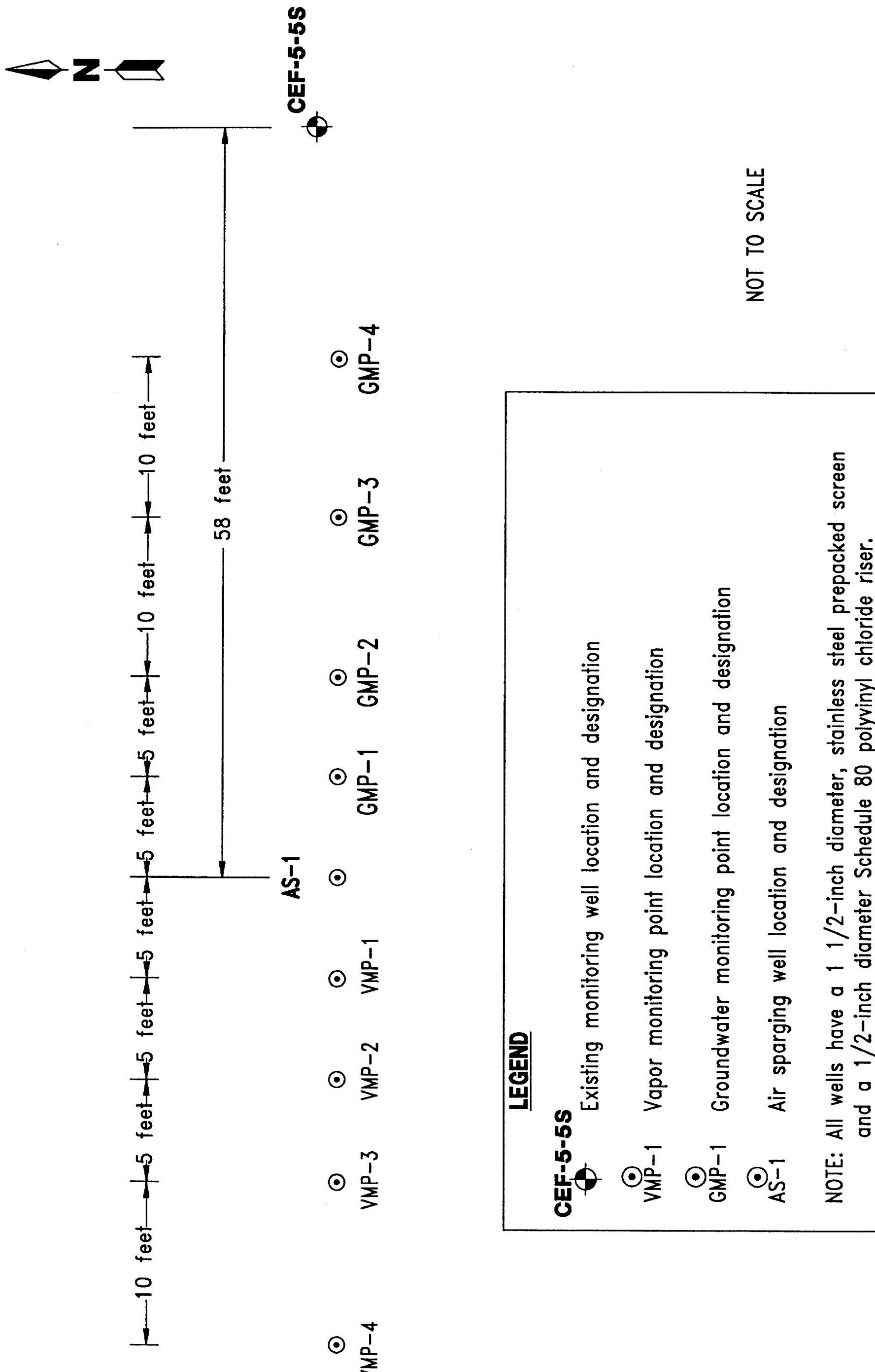

Fig. 7. Air sparging plan view.

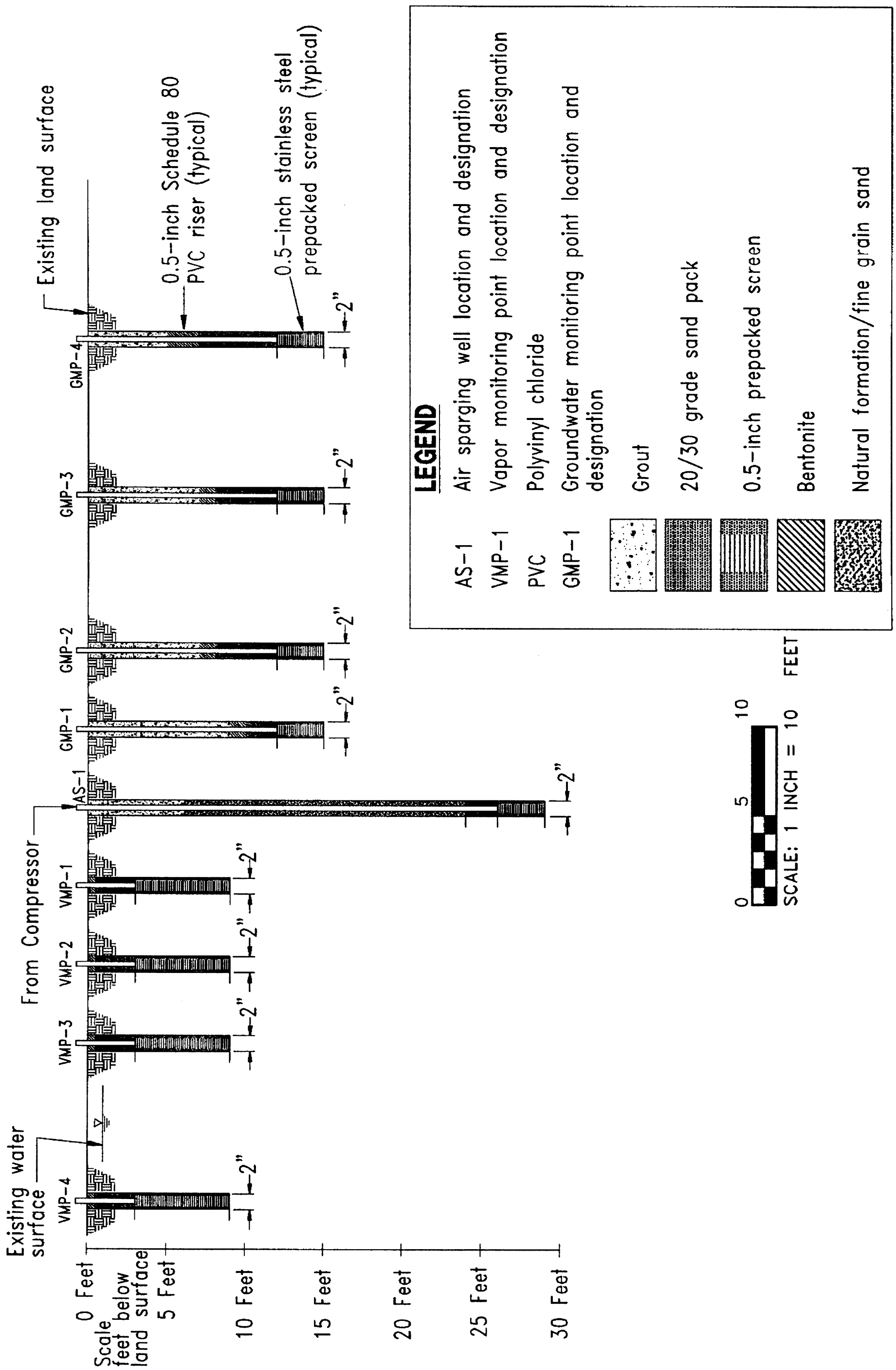

Fig. 8. Air sparging monitoring point cross-section.

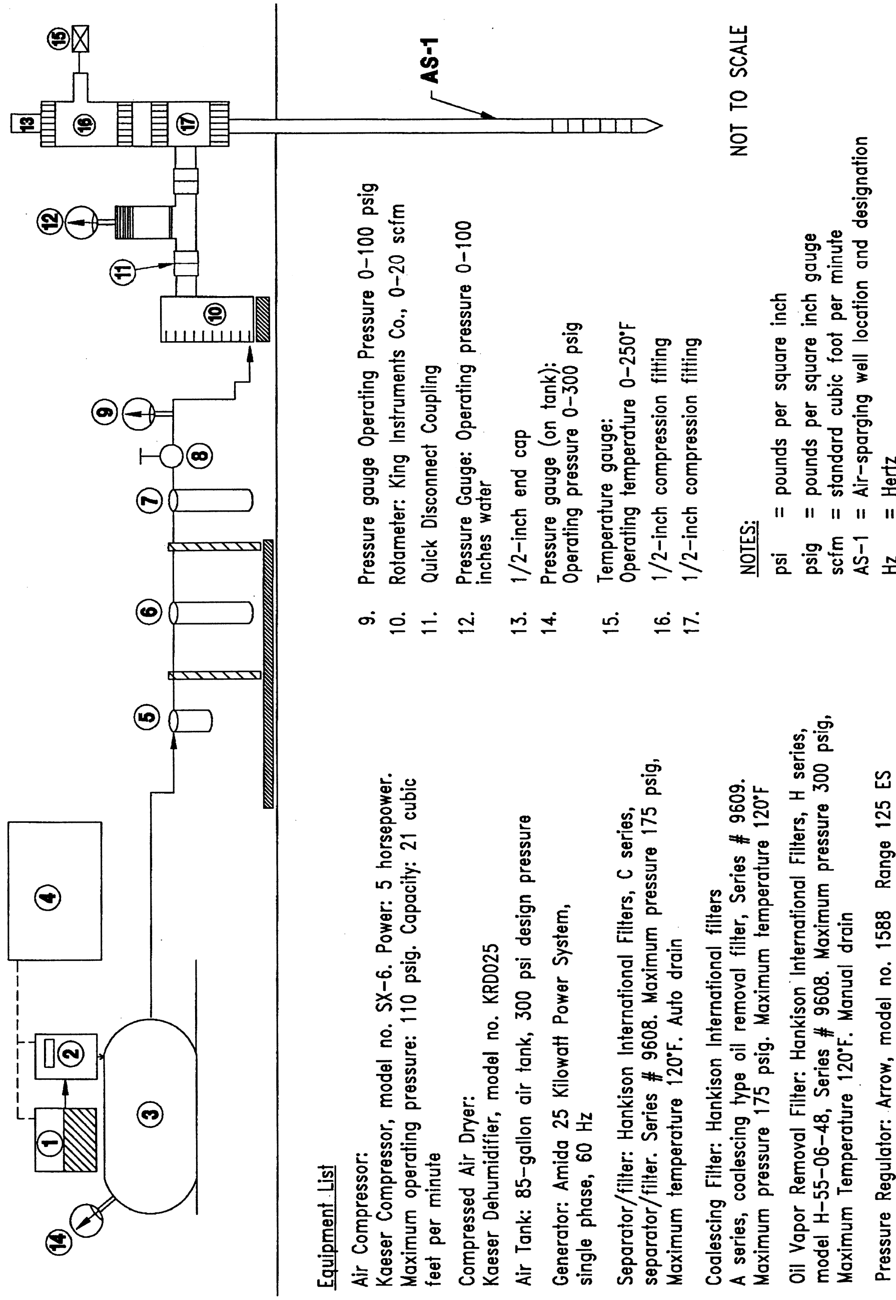

Fig. 9. Air sparging equipment.

and sparged air data. Fig. 7 is a plan view showing well locations, and Fig. 8 is a profile showing construction details.

Fig. 9 is a diagram illustrating the sparging equipment layout. Baseline sampling and equipment setup were completed on June 9, 1997. The 72-h pilot test was conducted from June 10 through June 13, 1997.

4. Test execution and results

Following baseline sampling, sparging began with an air flow rate of 3 cfm. This flow rate was held constant during the first 24 h of testing. The initial plan was to sparge at 3 cfm for the first 24 h, 6 cfm for the second 24 h, and 9 cfm for the last 24 h. However, due to the high water table, it became readily apparent that flow rates higher than 3 cfm would cause excessive spurting of water from the monitoring wells and, in essence, prevent collection of meaningful data. Therefore, during the second and third days, the flow rate was reduced to 2 and 1 cfm, respectively.

During the 72-h test, the following data were collected:

1. Water-level elevations,
2. Visual observations,
3. Dissolved oxygen and carbon dioxide concentrations in groundwater,
4. Flame ionization detector (FID) readings,
5. Air samples,
6. Groundwater samples.

4.1. Water-level elevations

The water level fluctuations at each monitoring point were plotted as a change in head from the initial equilibrium level. Fig. 10 illustrates the relation between groundwater mounding and time for each VMP. Initially, a water table mound of more than 2 ft was formed within 15 ft of the sparge point while the compressor was supplying air at 3 cfm. The overall dynamic of mound formation and return to equilibrium occupied a time period of about 20 h, with the peak elevations occurring about 4–5 h after air flow initiation.

An abrupt drop in the water table of about 0.5–1.0 ft followed by a slow rise back to equilibrium conditions was recorded for VMPs 1, 3, and 4 immediately following the decrease in operating flow rates at 24, 48, and 72 h. The decreases in air flow rate presumably require reduced cross-sectional flow areas of the air channels, and the resulting groundwater flow into the void caused by these reductions causes a water level drop with subsequent recovery.

There is an observed inverse relationship between the degree of groundwater mounding and the distance from the sparge point. One exception is at VMP-2 where a preferential air flow channel appears to have developed directly from AS-1. VMP-2 spurted groundwater throughout the test, which is shown by the straight line for VMP-2 on Fig. 10 beginning at the start of the test and continuing until the test end.

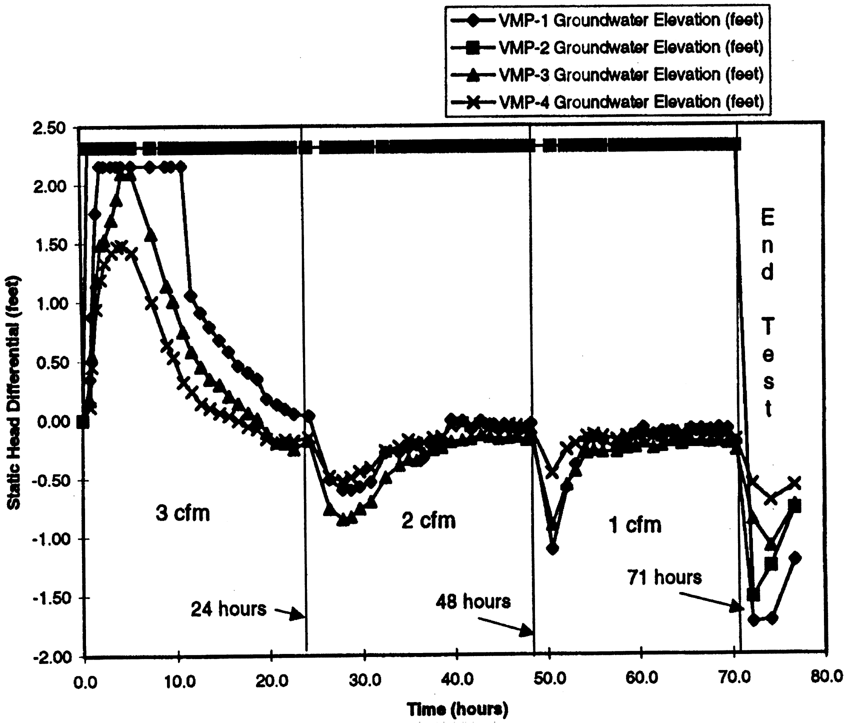

Fig. 10. Water table fluctuations vs. time.

A slight drop (approximately 3 in.) is apparent between the static water table elevation at the beginning of the test and that at the test conclusion. Considering the high water table conditions prior to testing, this differential is likely due to a normal water table recession over the 3-day time period of the test. Groundwater mounding results indicate that a radius of influence greater than 25 ft would be expected for flow rates in excess of 1 cfm. Twenty-five feet was the distance between VMP-4 (the most distant water level monitoring point) and the air sparge point.

4.2. Visual observations

Because a large portion of Site 5 to the south, east, and southeast was covered with standing water (puddles) throughout the test, observation of air bubbles rising to the water surface offered strong visual evidence of the radius of influence. While the compressor was operating at 3 cfm, the maximum distances from AS-1 to bubble clusters were:

- 57 ft in the north–northwest direction,
- 39 ft in the northeast direction, and
- 44 ft in the southeast direction;

at 2 cfm, the maximum distances were:
- 44 ft in the north–northwest direction,
- 36 ft in the northeast direction, and
- 40 ft in the southeast direction;

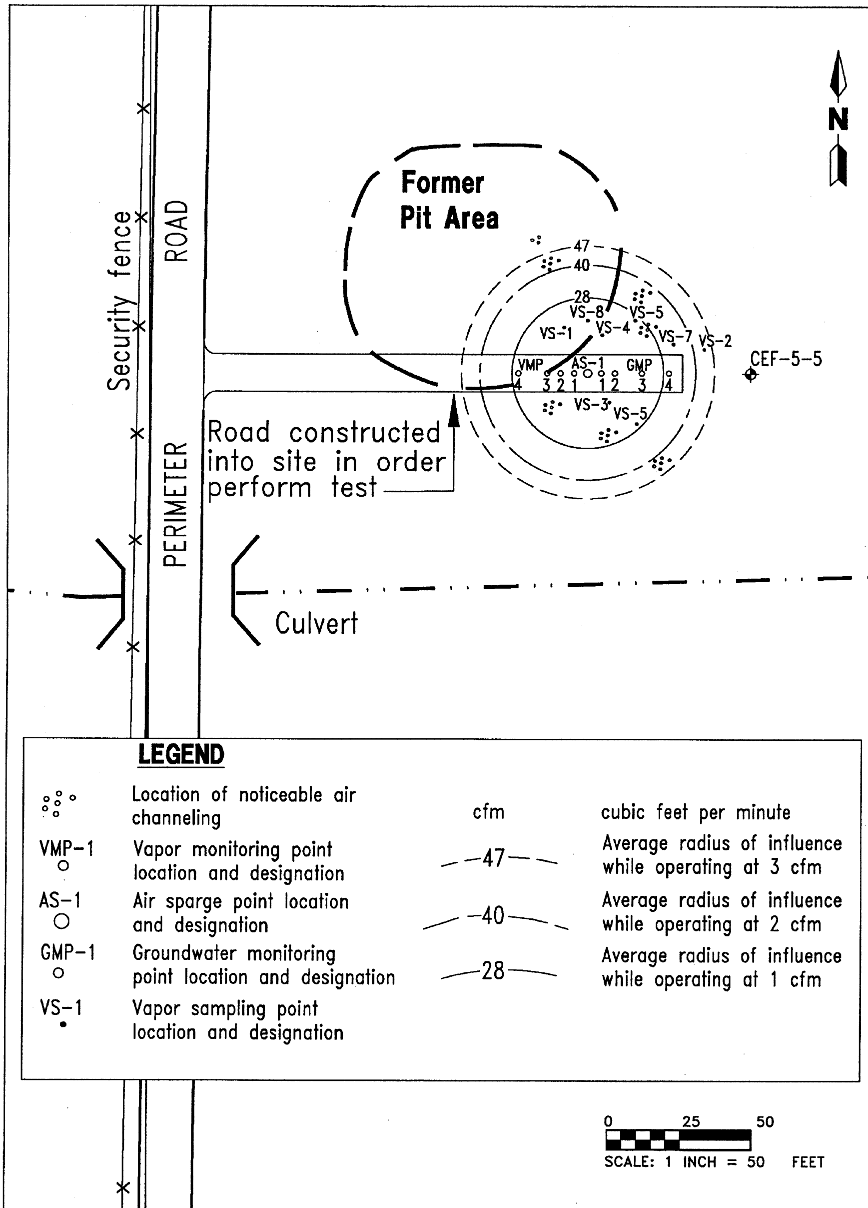

Fig. 11. Air sparge radius of influence.

and at 1 cfm, the maximum distances were:
- 43 ft in the north–northwest direction,
- 37 ft in the northeast direction,
- 22 ft in the southeast direction,
- 15 ft in the southwest direction, and
- 21 ft in the south direction.

These distributions show some preferential channeling throughout the site, which is due to slight differences in permeability caused by soil heterogeneity. The average radius of influence for each operating flow rate based on visual observation is 28, 40, and 47 ft for 1, 2, and 3 cfm, respectively. These radii of influence are shown graphically on Fig. 11, along with the bubble cluster locations and vapor sampling points.

4.3. Dissolved oxygen and CO_2 in groundwater

Dissolved oxygen and CO_2 data for each GMP are plotted on Figs. 12–15. The graphs illustrate an inverse relation between dissolved oxygen and CO_2 in three of the four wells. This is due to the sparged air supplying oxygen to the groundwater and, at the same time, apparently providing a stripping mechanism for removal of CO_2 as well as VOCs.

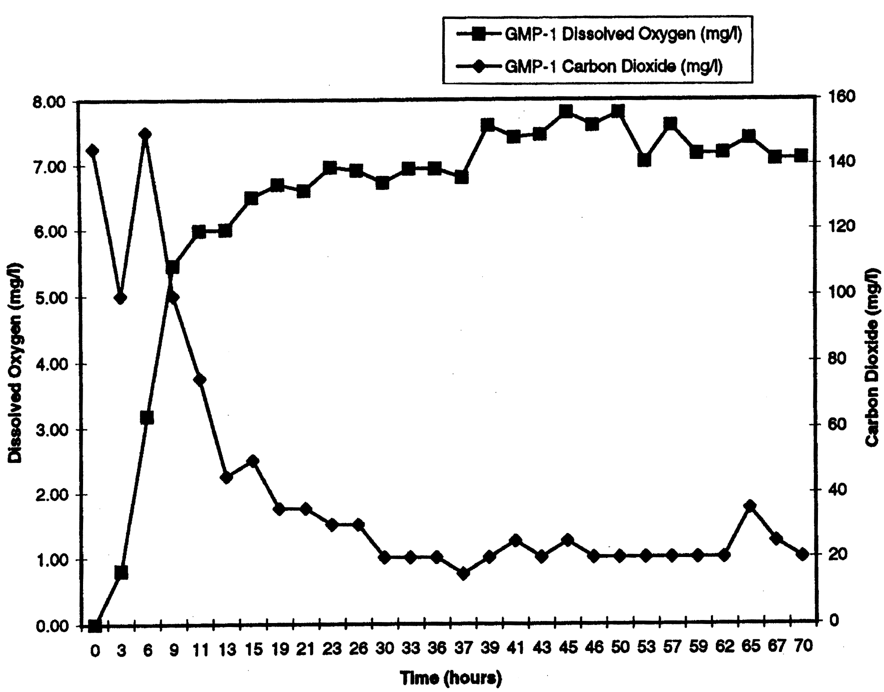

Fig. 12. Dissolved oxygen and carbon dioxide in GMP-1.

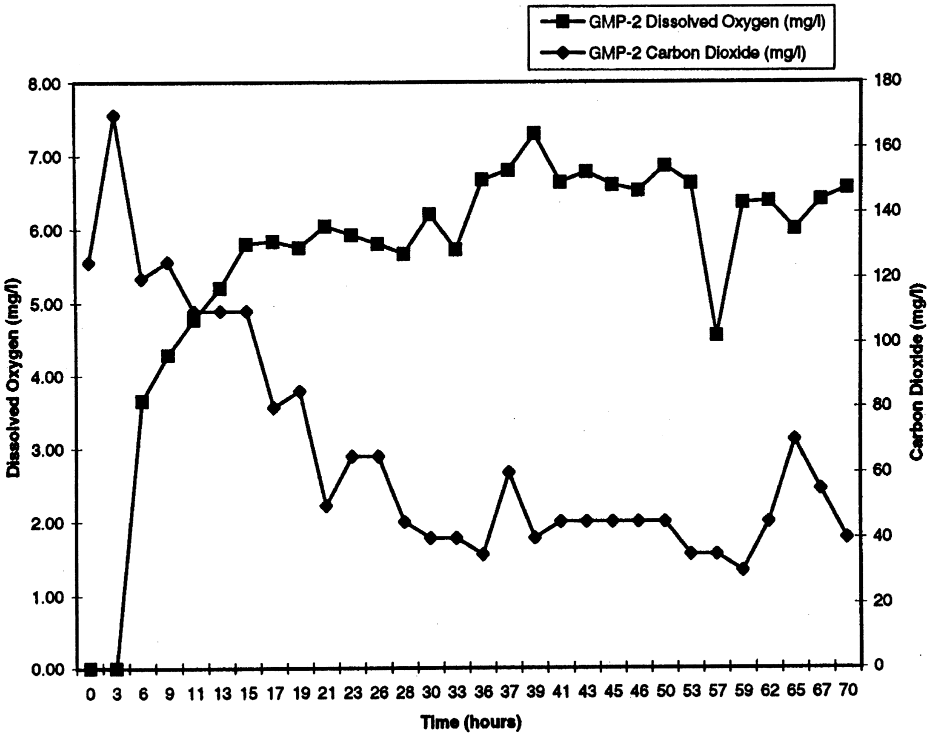

Fig. 13. Dissolved oxygen and carbon dioxide in GMP-2.

Also indicated on the time history graphs of dissolved oxygen is the nature of growth of the radius of influence. GMP-1, 5 ft from AS-1, shows an increase in the dissolved oxygen in groundwater beginning within about 2 h of initiating sparging, reaching a maximum of about 7 mg/l. GMP-2, 10 ft from AS-1, began to show an increase in dissolved oxygen after approximately 4 h of testing, and approached a maximum of about 6.5 mg/l. GMP-4, 30 ft from AS-1, had a lag time of about 14 h before increased dissolved oxygen concentrations were observed, and the maximum concentration reached about 6 mg/l. Corresponding inverse behaviors are depicted for CO_2 concentrations.

Groundwater in GMP-3, 20 ft from the sparge well, did not experience an increase in dissolved oxygen, and there was no noticeable change in the CO_2 concentrations in groundwater collected from this point during testing. This is likely due to heterogeneities in the soil that restricted air flow near this point. Under a longer duration of operation, diffusion and other processes would likely affect this and other areas within the radius of influence that were not directly affected during this short pilot test.

Dissolved oxygen concentrations in groundwater, neglecting measurements made in GMP-3, indicate that the air sparging radius of influence was greater than 30 ft. CO_2 measurements support this observation.

The CO_2 concentrations in groundwater, neglecting GMP-3 measurements, offer an indication of the stripping action expected with air sparging. A continual decrease of

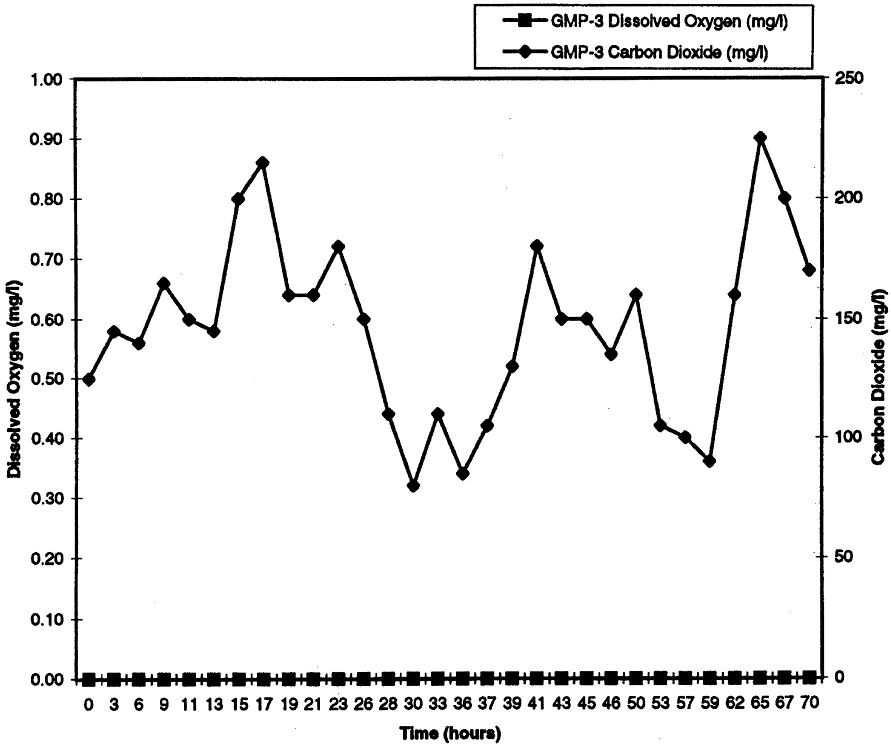

Fig. 14. Dissolved oxygen and carbon dioxide in GMP-3.

CO_2 concentration was observed throughout the first day of testing and into the second. By the middle of the second day, the CO_2 concentrations reached their minimum values where they remained throughout the test. The reduction in CO_2 concentration is greatest at the closest monitoring point (GMP-1 at $r = 5$ ft), and reduces as radius from the sparge well increases (see Figs. 12, 13 and 15). The CO_2 removal efficiencies vary from about 85% at $r = 5$ ft (GMP-1 decreased from 150 to 20 mg/l) to 73% at $r = 10$ ft (GMP-2 decreased from 150 to 40 mg/l) to 60% at $r = 30$ ft (GMP-4 decreased from 150 to 60 mg/l).

4.4. FID readings

A portable FID was used to measure VOC concentrations in the sparged air from the VMPs. Plots of vapor concentration vs. time for each VMP are provided on Figs. 16–19. Although these data were collected using a field instrument, relative concentrations compared favorably with analytical results from air samples collected during testing. These air samples and their results are discussed below.

Groundwater was spurting from VMP-2 throughout the test, indicating that a relatively large air channel had developed between AS-1 and the well screen at VMP-2

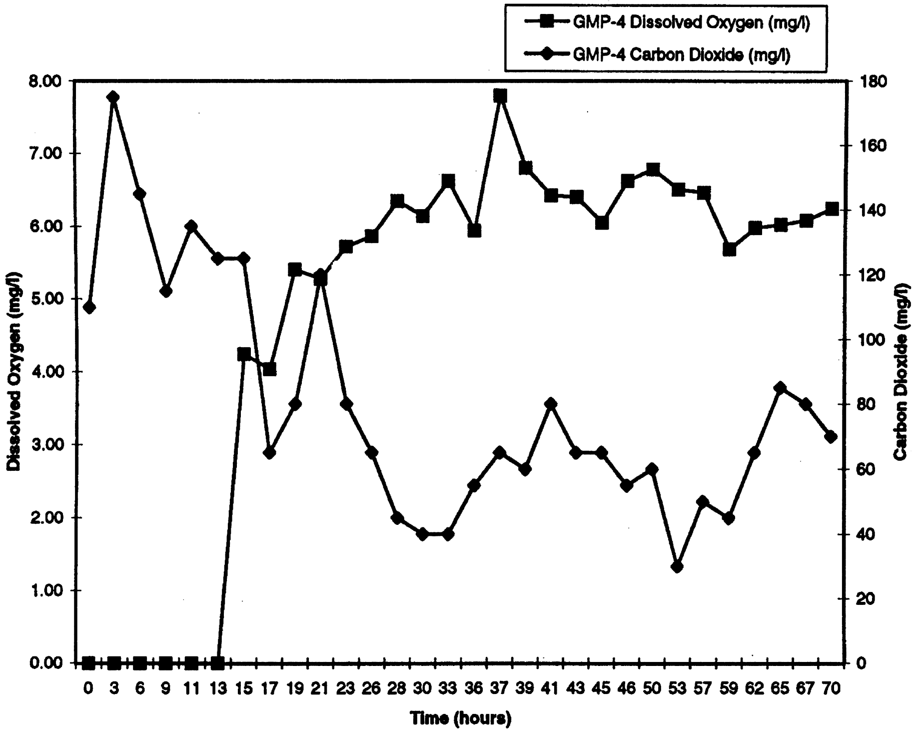

Fig. 15. Dissolved oxygen and carbon dioxide in GMP-4.

(evidence of this is seen on Fig. 17). This made consistent measuring of vapor concentrations difficult, and data obtained from this point was not used for interpretation of the pilot test performance.

Fig. 16 is a plot of vapor concentrations vs. time prepared for VMP-1, 5 ft from AS-1. During days 2 and 3, while the air sparging rates were 2 and 1 cfm, respectively, vapor concentrations dropped abruptly at mid-day from about 200 and 150 ppmv, respectively to less than 10 ppmv Fig. 18. shows elevated readings at VMP-3 (15 ft from AS-1) during the first 24 h of testing, then much lower readings (less than 10 ppmv) during days 2 and 3. The vapor concentrations measured in VMP-4 remained at low levels (less than 15 ppmv) throughout the test (see Fig. 19).

Using the daily maximum FID readings recorded in ppmv for VMP-1, VMP-3, and VMP-4 and the average molecular weight of the VOCs detected in air samples collected, an estimate of air emissions can be made by multiplying by the known air-sparge flow rate. Based on these estimates, on a per sparge point basis, a maximum of 0.26 lb/day of VOCs will be emitted while the compressor is operating at 3 cfm; 0.08 lb VOCs/day at 2 cfm; and 0.03 lb VOCs/day at 1 cfm.

FID readings support the CO_2 findings of a decreasing stripping efficiency with distance from the sparge point. At a radius of 5 ft, readings above 100 ppmv were measured periodically at each flow rate. However, FID readings measured at 15 ft from

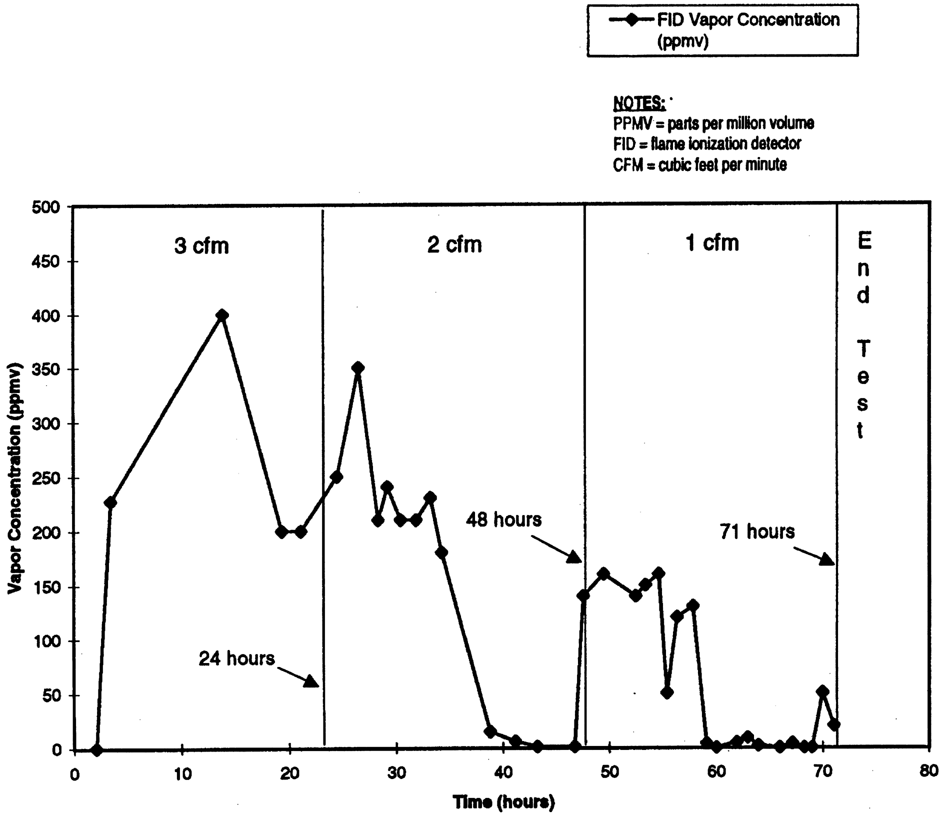

Fig. 16. Vapor concentration vs. time for VMP-1.

the sparge point showed high concentrations (greater than 100 ppmv) only while sparging at 3 cfm; otherwise these concentrations remained below 15 ppmv. Concentrations measured at 25 ft from the sparge point were not above 15 ppmv at any point during testing.

4.5. Air samples

Tedlar® bag air samples were collected for further evaluation of the vapor emissions from the site. Because of the high water table, coupled with the mounding, the VMP wells were virtually useless for collecting vapor samples using Tedlar® bags. In order to obtain samples for laboratory analysis, vapor was collected from the air channels, identified by bubbling through puddles, at varying distances from the sparge point. These samples were collected directly from plastic bags that were placed over visible air channel exit points. The bags were sealed by placing mud around the outside of the opening of the bag. The bags were allowed to fill to capacity, and the sample was then transferred to a Tedlar® bag for shipping and analysis.

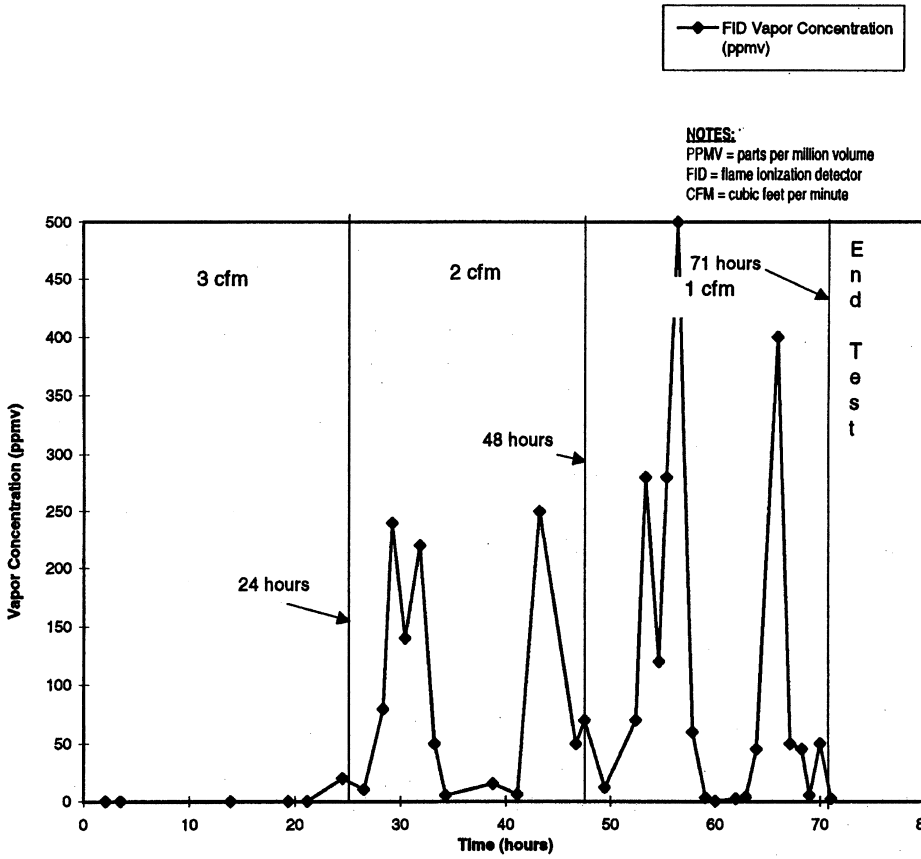

Fig. 17. Vapor concentration vs. time for VMP-2.

Vapor sample locations are shown on Fig. 11 and are designated VS-1 through VS-8. VS-1 through VS-3 were collected while the compressor was operating at a sparge rate of 3 cfm; VS-4 through VS-6A, at a sparge rate of 2 cfm; and VS-6B through VS-8, at a sparge rate of 1 cfm. These air samples were taken at the end of each test day to monitor the change of emission rates with flow rates and time.

Based on the USEPA Method T014 analyses of the grab samples, the average emission rate for day 1 while the compressor was operating at 3 cfm was 0.06 lb VOCs/day (average of three samples). For day 2 (operation flow of 2 cfm) the average mass of emission rate of three grab samples was 0.02 lb/day. While operating at 1 cfm in day 3, the emission rate was estimated to be 0.01 lb/day from the analysis of one grab sample (two additional samples collected on day 3 were lost by the shipping company). These emission rates are 3–4 times lower than those estimated from FID readings. Fig. 11 indicates that the grab sample locations ranged in distance from 13 to 42 ft from the sparge well, while the FID readings were obtained from the VMP locations which ranged from 5 to 25 ft from the sparge well. As previously documented,

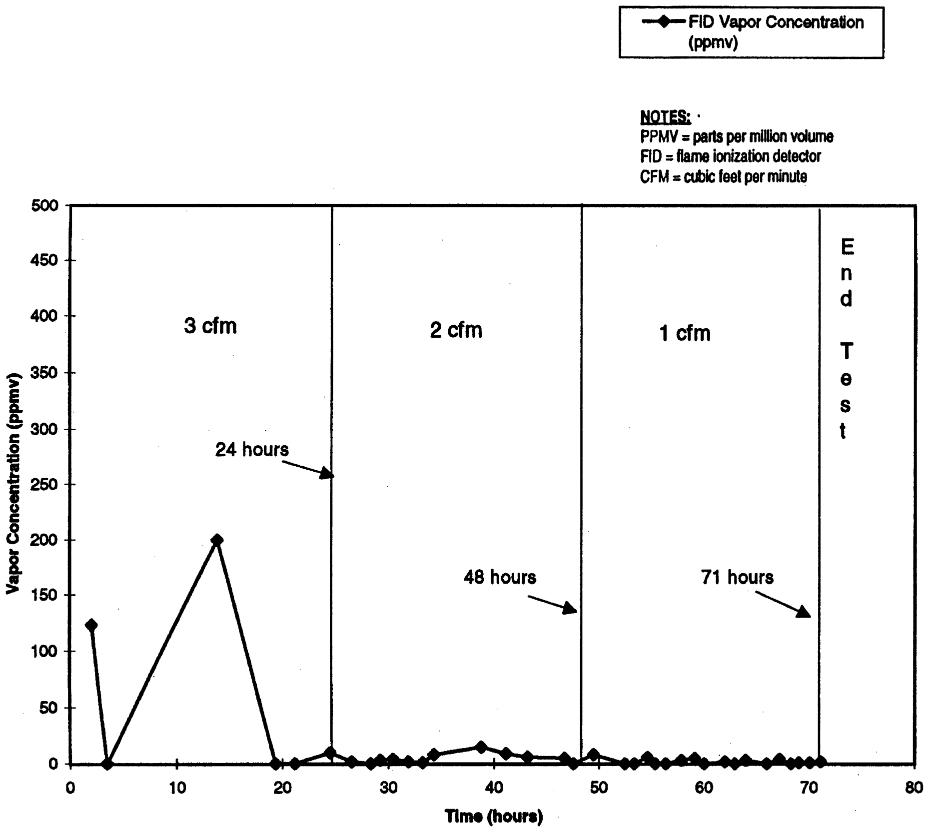

Fig. 18. Vapor concentration vs. time for VMP-3.

the stripping efficiency is greater closer to the sparge well, and this difference in VOC concentrations confirms the earlier observations.

The Florida Petroleum Contamination Site Cleanup Criteria (Chapter 62-770 of the Florida Administrative Code [FAC]) [4] indicate that off-gas treatment is required until total VOC air emissions are 13.7 lb/day or less. Based on the average emissions estimated using the air sample analyses during this test and the estimated number of sparge points necessary, it is unlikely that an exceedance of 13.7 lb/day would occur. This is also the case if the maximum values (estimated from FID readings) are considered. A comparison of the maximum mass of VOCs emitted per day and the average mass of VOCs emitted per day is provided in Table 1.

4.6. Groundwater samples

Groundwater samples were collected from AS-1, GMP-2, and GMP-4 prior to testing, GMP-2 and GMP-4 at the midpoint of testing, and from all three points at the test conclusion. The results of these analyses are presented in Table 2.

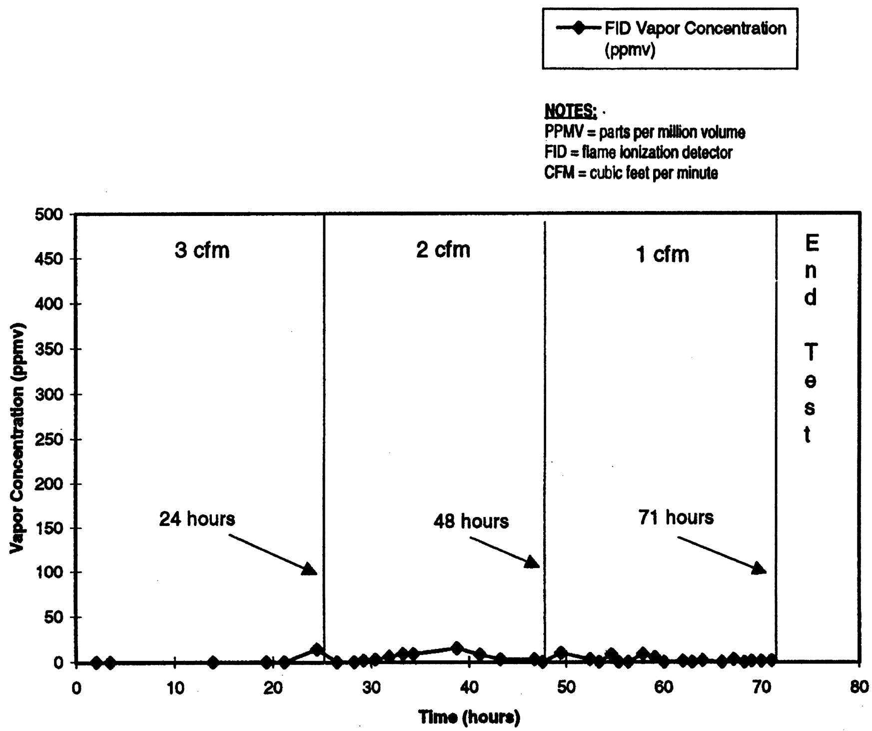

Fig. 19. Vapor concentration vs. time for VMP-4.

In AS-1, no VOCs were detected above target cleanup levels before or after testing. This indicates that the sparge point was located beneath the contaminated zone, which is recommended for sparging applications.

Groundwater collected from GMP-2 showed contaminant reductions for each of the benzene, toluene, ethylbenzene, and xylenes (BTEX) compounds during testing. Concentrations of TCE showed a reduction at the test midpoint but rebounded at the test end.

Table 1
Comparison of average and maximum air emissions

	Day 1	Day 2	Day 3
Air sparge flowrate (cfm per sparge point)	3	2	1
Maximum VOC emission rate based on FID readings (lb/day)[a]	0.26	0.08	0.03
Average VOC emission rate based on grab air samples and laboratory analyses (lb/day)	0.06	0.02	0.01

[a]The daily maximum FID reading was used in the development of this emission rate.
cfm = cubic feet/min. FID = Flame ionization detector. lb/day = Pound per day. VOC = Volatile organic compound.

Table 2
Groundwater data summary

Compound detected	Day 1 concentration (μg/l)	Day 2 concentration (μg/l)	Day 3 concentration (μg/l)
Air Sparge Well (AS-1)			
Methylene chloride	0.17	NS	0.14
Acetone	20	NS	66
Carbon disulfide	0.099	NS	17
2-Butanone	6.2	NS	ND
Toluene	0.082	NS	ND
Total BTEX	0.082	NS	ND
Groundwater monitoring point 2 (10 ft from AS-1)			
Acetone	ND	230	270
Carbon disulfide	ND	1.2	4.4
Trichloroethene	**4.3**	1.9	**4.2**
Benzene	**3.6**	**1.7**	**1.3**
Toluene	42	20	23
Ethylbenzene	11	4.8	5.1
Xylenes (total)	98	53	58
Total BTEX	**155**	**80**	**87**
Groundwater monitoring point 4 (30 ft from AS-1)			
Acetone	ND	130	46
2-Butanone	ND	30	ND
Benzene	**1.2**	0.84	**1.2**
Toluene	11	6.6	12
Ethylbenzene	4.3	1.1	4.1
Xylenes (total)	20	11	18
Total BTEX	37	20	35

Values in bold are above MCLs or applicable or relevant and appropriate requirements.
BTEX = Sum of benzene, toluene, ethylbenzene, and total xylenes. MCL = Maximum contaminant level. μg/l = Micrograms per liter.ND = Not detected. NS = Not sampled.

In GMP-4, each of the BTEX compounds appears to have experienced some reduction during testing but rebounded following testing. An explanation for this may be the influx of groundwater from the surrounding area at GMP-4. Because this point served as the most distant monitoring point (30 ft from the sparge point), it is probable that during this short test, groundwater further away from the sparge point did not receive the degree of stripping experienced by groundwater closer to the sparge point. Therefore, VOCs in the intruding groundwater have not been volatilized during the short test period, and would be responsible for the observed concentration rebound.

5. Summary and conclusions

Results and findings from observations made in the field and analysis of the data collected from the Site 5 air sparging pilot test are summarized below.

- The 72-h air sparge test was conducted with an initial air flow rate of 3 cfm for the first day, then 2 cfm for the second day, and finally 1 cfm for the last day. The water levels in the vapor monitoring probes initially rose about 2 ft during the first 4–5 h of the test, then receded back to pretest equilibrium levels over the next 15 h, such that the total duration of water table mounding was about 20 h. A small (about 0.5 ft) water table drop, with subsequent recovery to equilibrium level, occurred each time the air sparging rate was decreased.
- Visual observations of bubbles rising through water, which, due to recent rainfall, was ponded on the ground surface in the area of the pilot test, allowed the radius of influence of the air sparging to be determined by direct observation. Although there is considerable variation depending on direction from the sparge well, the average radius of influence varied from about 30 ft at 1 cfm to about 40 ft at 2 cfm to about 50 ft at 3 cfm. Increases in dissolved oxygen from 0 to 6 mg/l confirm that the radius of influence is at least 30 ft (the largest distance to a monitoring point); and the significant water table response to changes in air flow rate at the last VMP would indicate that the radius of influence is larger than 25 ft.
- The air sparge system was capable of increasing the dissolved oxygen from zero to 6–7 mg/l within 12–15 h of air sparging channels reaching a given location. The dissolved oxygen levels then remained at these levels for the remainder of the 72-h test period. At the closest monitoring point ($r = 5$ ft), the dissolved oxygen began to increase almost immediately; however, for monitoring points at large radii there was a lag time of 3 h at a radius of 10 ft and 13 h at a radius of 30 ft before the dissolved oxygen began to increase. This is apparently a measure of the time it took for the air channels to become developed out to the larger distances from the sparge well.
- The CO_2 levels decreased from about 150 mg/l everywhere to about 20 mg/l at $r = 5$ ft and to about 50 mg/l at $r = 30$ ft within a time period of about 24 h. These levels then remained constant for the rest of the 72-h test period. The CO_2 was apparently stripped out of the groundwater by the air sparging. The CO_2 data provide another line of evidence that stripping occurred at least 30 ft from the sparge well.
- Dissolved oxygen concentrations in groundwater collected from GMP-3 (20 ft from the sparge well) remained at zero throughout the test. CO_2 concentrations at GMP-3 remained, on average, at about 150 mg/l. This was likely due to a subsurface obstruction such as a thin clay lens or other heterogeneities in the soil, which shielded this area from sparging influence.
- Measurement of VOC concentrations in sparged air collected at the ground surface revealed that the rate of VOC mass removal during the pilot test was 0.06 lb/day at a sparge rate of 3 cfm, 0.02 lb/day at 2 cfm, and 0.01 lb/day at 1 cfm. These removal rates were generally confirmed by the FID measurement of vapor concentration at the VMPs. Given that the total mass of VOCs in the plume to be remediated has been estimated to be 13.2 lb (based on 1995 data), it would appear that air sparging will effect a rapid cleanup of the VOCs in the Site 5 groundwater plume.
- At 3 cfm air sparge rate, the mass removal rate is estimated to be 0.06 lb/day, and the number of sparge points needed to cover the plume area is less than 10; therefore the total air emissions would be less than 1 lb/day VOCs, which is well within the 13.7 lb/day limit for air emissions proposed in Chapter 62-770, FAC. It would appear that an

air sparge flow rate of 5 cfm per sparge point could be used and still not exceed an air emissions rate of 1 lb/day.

• Most of the SVOCs are not readily conducive to air sparging (i.e., Henry's law constant $> 10^{-5}$ atm m^3/mol). However, the oxygen added to the groundwater will stimulate aerobic bacteria, which are known to be very effective at degrading petroleum contamination and, therefore, will assist the air sparging process in remediation of the groundwater contamination. Air sparging is expected to indirectly remediate SVOCs with low Henry's law constants via enhanced bioremediation.

In conclusion, the air sparging pilot test has shown that this remedial technology will be very effective in the cleanup of the Site 5 groundwater contamination. Therefore, air sparging should be the remedial technology implemented at Site 5.

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