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Remedial Investigation/Feasibility Study
Galena Airport, Alaska

Treatability Study Report

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13. ABSTRACT (Maximum 200 words)

The USAF contracted Radian Corporation to perform treatability studies to evaluate soil vacuum extraction (SVE) and biodegradation technologies for remediating soils contaminated with motor and jet fuel at the Petroleum, Oils, and Lubricants (POL) Tank Farm, Galena Airport, Alaska. This technical report describes the experimental methods and interprets the analytical and operational results from the bench-scale biotreatment tests and pilot-scale SVE tests conducted between July 1992 and February 1994.

An initial pilot test conducted at the Galena Airport POL site during July to September 1992 demonstrated the effectiveness of SVE for removing volatile organic compounds (VOCs). Beginning in August 1993, a second pilot SVE test was conducted for a six-month operational period. This pilot test design included two study areas, each equipped with a central vapor extraction well; a series of air and/or steam injection points; and soil, soil gas, and groundwater monitoring points. Monitoring results show that average VOC removal rates by the twin SVE systems ranged between 50 to 380 kg/day. In situ biodegradation rates up to 8 mg/kg/day were also measured in the vadose-zone soils during the second pilot test. Similar biodegradation rates were observed in bench-scale tests. The increase in biological activity is attributed to the higher subsurface oxygen levels induced by SVE operation.

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This report has been prepared for the United States Air Force by Radian Corporation for the purpose of aiding implementation of a final remedial action plan under the Air Force Installation Restoration Program (IRP). Since the report relates to preliminary results from a pilot remedial action demonstration project, its release before an Air Force final decision on remedial action may be in the public's interest. The limited objectives of this report and the ongoing nature of the IRP, along with the evolving knowledge of site conditions and the chemical effects on the environment and health, must be considered when evaluating the report, since subsequent facts may become known that may make this report premature or inaccurate. Acceptance of this report in performance of the contract under which it is prepared does not mean that the Air Force adopts the conclusions, recommendations, or other views expressed herein, which are those of the contractor only and do not necessarily reflect the official position of the United States Air Force.

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Section 1
SUMMARY OF TREATABILITY STUDY

1.1 Background

The U.S. Air Force (USAF) is conducting a Stage 3 remedial investigation/feasibility study (RI/FS) as part of the Installation Restoration Program (IRP) at Galena Airport and Campion Air Force Station in Alaska. A treatability study (TS) was conducted as part of the FS, including bench-scale and pilot-scale tests, to evaluate soil remediation technologies for the Petroleum, Oils, and Lubricants (POL) Tank Farm site (ST005) at Galena Airport. The treatment technologies tested include soil vacuum extraction (SVE), free-phase hydrocarbon removal, and enhanced bioremediation. These remedial technologies were previously recommended for cleanup of hydrocarbon-contaminated soils at Galena Airport in the *Stage 2 RI/FS Report* (USAF, 1991) and the *Detailed Analysis of Treatment Alternatives* (DATA; USAF, 1992a).

Unique hydrological conditions are present at the site, causing contaminants to spread both vertically and horizontally. The site features groundwater that fluctuates annually over a 20-ft vertical range, discontinuous permafrost layers, and isolated lenses of floating, light nonaqueous phase liquids (LNAPL), presumably motor and jet fuels.

1.2 Treatability Study Program

On the basis of recommendations of the DATA, bench-scale and pilot-scale treatability studies were conducted to evaluate in situ remediation technologies for soils contaminated with gasoline and jet fuel. The TS program consisted of the following activities:

1. A Phase I pilot-scale test of an SVE system at the Galena Airport POL Tank Farm (July through September 1992);

2. A Phase I bench-scale test to evaluate treatments that could potentially accelerate hydrocarbon biodegradation rates in soils (conducted in Radian Corporation's Austin laboratory from September through December 1992);

3. A Phase II pilot-scale test of enhanced SVE systems that incorporated in situ air sparging (IAS) and in situ steam injection (conducted at Galena Airport from July 1993 to February 1994); and

4. Free-product (LNAPL) recovery testing (conducted during September 1992, July 1993, and April 1994).

1.2.1 Phase I Pilot-Scale Test

The initial (Phase I) pilot-scale test began in July 1992 and ran through the end of September. Conducted in the POL Tank Farm area, the pilot-scale treatment system consisted of a single extraction well in the unsaturated-zone soil connected to a 6-hp electrical blower. The average blower flow rate was approximately 72 standard cubic feet per minute (scfm). A plastic soil cover helped prevent air short circuiting and direct subsurface soil vapors toward the extraction well. The extracted vapor stream was treated with granular activated carbon contained in 55-gal. drums to capture the volatile organic compounds (VOCs).

The SVE system removed approximately 3200 lb of VOCs during the two-month period of operation. Rough mass balance calculations indicated that the mass of hydrocarbons removed probably exceeded the initial mass present within the SVE-influenced zone at the start of the test. It was anomalous, therefore, that no significant reduction in the residual hydrocarbon concentrations in the vadose-zone soils was observed during the test. The reduction of hydrocarbon contaminants was limited by two hydrologic processes: 1) a continual decline in the water table occurred during the operating period, thus exposing deeper portions of the hydrocarbon smear zone; the water table fluctuation increased the mass of VOCs accessible to the gas phase present within the SVE zone of influence; and 2) a layer of floating free-phase hydrocarbons was present over a portion of the test site; this layer provided a continual source of VOCs. Despite these limitations, the initial pilot test demonstrated that a medium-sized SVE system could attain a large radius of influence (at least 60 ft) and high VOC removal rates while increasing the subsurface oxygen levels. The latter effect should enhance in situ biodegradation.

1.2.2 Phase I Bench-Scale Test

Seven different soil amendment/treatment conditions were tested in the bench-scale soil incubation study. The treatment variables included gas-phase oxygen content (2% to 21%), nutrient addition, moisture content, and inoculation with a commercial microbial consortium. Respirometry tests and residual hydrocarbon measurements were used to evaluate biotreatment in a simulated cold climate.

The laboratory test results showed that significant biological activity occurred in all treatments. Estimated biodegradation rates ranged from 1.2 to 5.7 mg/kg/day. Total petroleum hydrocarbon concentrations decreased by 47% to 73% during the 97-day incubation period. The bioaugmentation treatment (inoculation with commercial bacteria) and the unamended treatment at 14% oxygen showed the best overall reaction rates. The bench-scale test demonstrated the feasibility of using biological processes for the remediation of soils at the POL Tank Farm.

1.2.3 Phase II Pilot-Scale Test

Phase II pilot-scale testing of an enhanced SVE process in the POL Tank Farm began in August 1993 and continued until early February 1994. The objective was to evaluate further in situ techniques for soil and groundwater remediation, including air sparging and steam injection. A remediation system was designed and demonstrated on two adjacent test cells. Each cell was equipped with a central vapor extraction well and a series of air sparging wells (one cell also included steam injection wells). Site conditions were monitored monthly using a network of soil vapor probes, groundwater monitor wells, and soil sampling locations. The pilot-scale systems were designed and weatherized for winter operation. Except for the steam injection system, which experienced several extended outages related to poor feedwater quality, the systems were run continuously throughout the study period other than for brief periods related to power outages, activation of safety switches, and monitoring events.

The East Cell used air sparging points in the groundwater zone upgradient to the direction of groundwater flow of the SVE well; the West Cell was similar but included steam injection points upgradient of the air sparging points. Hydrocarbon concentrations in the subsurface soils were dissimilar in the two cells, preventing a direct comparison of the technologies.

The test results indicated that VOC removal rates averaged around 380 kg/day in the West Cell and 50 kg/day in the East Cell. The removal rates for VOCs did not decline but remained steady throughout the pilot test, despite the six-month period of SVE operation. This response is attributed to the presence of a free-product layer in the subsurface and to the declining water table, which exposed fresh reserves of hydrocarbons throughout the study.

The geology at the POL Tank Farm was very conducive to SVE treatment. The permeability of the subsurface soils to air ranged from 30 to 240 darcys. Flow rates for the Phase II SVE system ranged between 120 and 150 scfm, and the effective radius of influence for both cells was determined to be between 100 and 200 ft.

In situ soil biodegradation rates were estimated at values up to 8 mg/kg/day in the West Cell. The average biodegradation rate was 3.2 mg/kg/day in the West Cell and 0.1 mg/kg/day in the East Cell. Oxygen levels increased to near-atmospheric conditions within five days of system startup in both areas. Biological activity was significantly higher in the far-western portion of the study site where the highest respiration rates, soil temperatures, and initial hydrocarbon concentrations were found. Soil temperatures increased in that area throughout the operating period, despite the falling ambient temperatures. By February, groundwater temperatures were beginning to rise as well. These observations indicated that biological activity in the soil at the POL Tank Farm was enhanced by the increased oxygen levels in the vadose zone, which were induced by the SVE system.

1.2.4 LNAPL Recovery Testing

Phase I—Two 6-in. wells were installed in the POL Tank Farm to test recovery of LNAPL during Phase I of this study.

Baildown testing was performed on one of these wells and a nearby monitoring well (the second recovery well did not contain sufficient floating product to allow testing). Maximum apparent product thicknesses observed following baildown were around 0.4 ft.

The estimated true LNAPL thickness in the formation for recovery well 05-RW-01 was 0.15 ft. For monitor well 05-MW-10, the corresponding product thickness was 0.03 ft. Because the magnitude of the water level change in both wells was so small and occurred so rapidly, there is some uncertainty as to the validity of the true product thickness estimates.

Phase II—The second phase of the LNAPL recovery test was to determine the recharge rate of the LNAPL into the well and to determine the true product thickness in the formation. This phase included more baildown testing on three wells as well as skimming tests with the pneumatic skimmer system. All of these Phase II recovery tests were conducted in July 1993 when the groundwater table was present in the silty strata in the upper portion of the hydrocarbon smear zone.

The baildown tests were performed first. Product recharge rates ranged from 0.1 to 2 gal. per day and estimates of true product thickness ranged from 0.03 to 0.4 ft.

For the initial skimming test on 05-RW-01, which was conducted over a three-day period, we were not able to reduce the extraction rate low enough to match the slow recovery rate of LNAPL into the well. Similar results were observed for recovery well 05-RW-2 and monitor well 05-MW-10.

A pneumatic hydrocarbon recovery (skimming) system (manufactured by Clean Environment Engineers) and a portable air compressor were used briefly to evaluate field recovery. Unfortunately, the close of 1993 field activities prevented the testing of the hydrocarbon skimmer system in the recovery wells.

Phase III—A third phase of recovery tests was conducted in April 1994 because it was believed that different hydrologic conditions exist before river breakup that should allow more effective LNAPL recovery. Baildown and skimming tests were used to determine the apparent product thicknesses in the monitoring wells, the true product thicknesses in the formation, and the range of expected recharge rates of LNAPL from the formation, as well as to evaluate the skimming ability of the pneumatic LNAPL recovery system further.

Baildown testing was performed on five wells (four in the POL area), and LNAPL skimming was attempted on one well (05-RW-02).

The skimming tests were only conducted for a short time (less than 8 hours) because difficulties caused by icing of the product discharge hose and failure of a pump valve prevented longer operation of the system. However, the product level in the well was reduced by just over 1 gal.

1.3 Future Considerations

A phased approach to remediating the POL Tank Farm is recommended on the basis of the results and findings of the treatability study. The TS has shown that product recovery is a necessary and practical remedial action. It has also shown that SVE is an effective treatment for vadose-zone soils contaminated with petroleum hydrocarbons. The free product recovery and SVE treatment systems could be run concurrently. Once the free product is sufficiently depleted, treatment of the dissolved-phase contaminants in the groundwater could be addressed by in situ air sparging or intrinsic bioremediation should a significant risk to human health or the environment be found to exist.

Section 2
SITE DESCRIPTION AND PROJECT BACKGROUND

In 1991, a *Detailed Analysis of Treatment Alternatives* was prepared as part of the IRP for four sites at Galena Airport: SS006 (Waste Accumulation Area), ST009 (Million Gallon Hill), ST005 (POL Tank Farm), and FT001 (Fire Protection Training Area). The purpose of the DATA was to compare treatment alternatives with respect to specified evaluation criteria and to select appropriate remediation technologies for hydrocarbon-contaminated soils (USAF, 1992a). In the DATA report, in situ treatment using a combination of SVE and bioventing was recommended for the major portion of contaminated soils at SS006, ST005, and those portions of FT001 that contain low levels of organic contaminants. In response to these recommendations, a TS consisting of bench-scale and pilot-scale tests was conducted in two phases to evaluate the effectiveness of SVE and bioremediation for the in situ treatment of contaminated soils at ST005, the POL Tank Farm. The general locations of Galena Airport and the TS site are shown in Figure 2-1.

2.1 Site Description

Galena Airport

Galena Airport is located in interior Alaska approximately 350 miles northwest of Anchorage and 280 miles west of Fairbanks. Galena Airport was formerly known as Galena Air Force Station and in this capacity served as the northernmost of the forward operating bases run by the USAF Pacific Air Forces (PACAF). The staff has been reduced significantly from its previous size of 330. Approximately 40 contractor personnel are currently assigned to the 166-acre base. The base and adjacent community of Galena (population approximately 550) are not connected by road to any other community; Galena is only accessible year round by airplane and in the navigable summer months by river craft.

The airport is located on a floodplain on the north bank of the Yukon River. Groundwater at the site fluctuates seasonally by approximately 20 ft. In the early summer, groundwater elevations typically reach levels of 5 to 8 ft below ground level (bgl) in response to the rapid seasonal rise of the Yukon River, and drop to 25 to 30 ft bgl by February.

Mean monthly temperatures range from a low of -11°F in January to 60°F in July. The average frost-free period is late May through early September. Detailed descriptions of the climate, geology, demographics, and operating histories for Galena Airport are presented in the *Remedial Investigation Technical Memorandum* (USAF, 1994).

POL Tank Farm

The POL Tank Farm is located north of the airstrip and east of the base housing complex. Figure 2-2 shows the location of the Phase I and Phase II TS areas at the POL Tank Farm. The topography is generally flat, except for the earthen dikes surrounding the fuel storage tanks. Vegetation on the site is generally low and sparse except for stands of willows along the dike slopes.

The geology of the POL Tank Farm site consists predominantly of recent alluvial deposits from the Yukon River. The site stratigraphy consists of two main units, which are covered by a gravelly sand fill unit in some areas of the POL Tank Farm. The upper unit consists of a silt or silty sand that is 8 to 10 ft thick and contains abundant wood fragments and other organic matter. The lower unit is composed of sand and gravel. Drilling and well installation in the sand unit was complicated by the substantial heave of the sands in the saturated zone. In undisturbed, vegetated terrain, permafrost occurs as isolated lenses or as continuous layers beginning 10 ft bgl. However, its distribution is sporadic and largely absent at the POL Tank Farm.

The POL Tank Farm formerly contained as many as 33 tanks, which were used to manage jet fuel, gasoline, diesel, and other fuels used at Galena Airport. All but five of the jet fuel tanks were removed in the fall of 1993; two aboveground tanks that contain

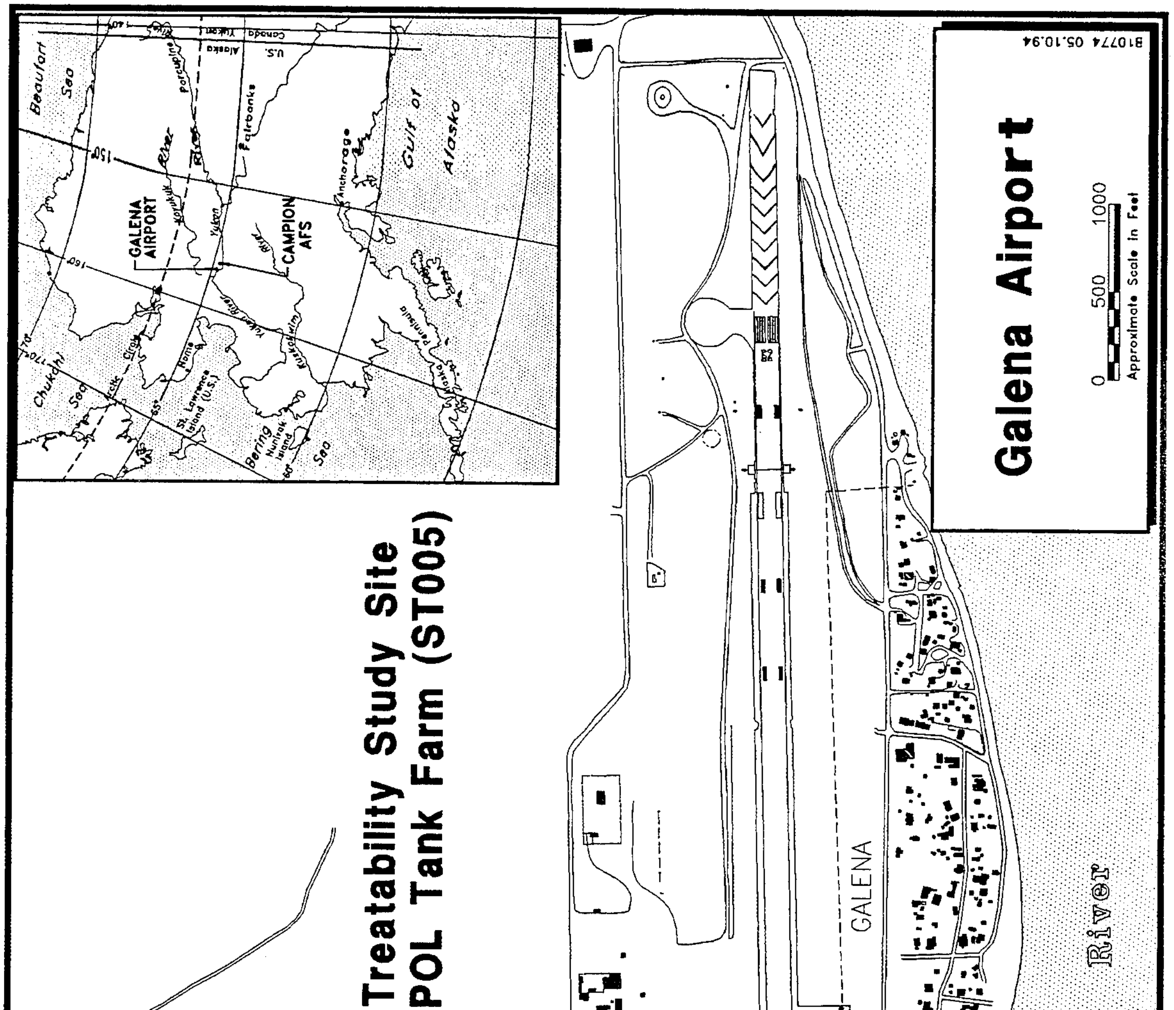


Figure 2-1. General Locations of Galena Airport and the Treatability Study Site

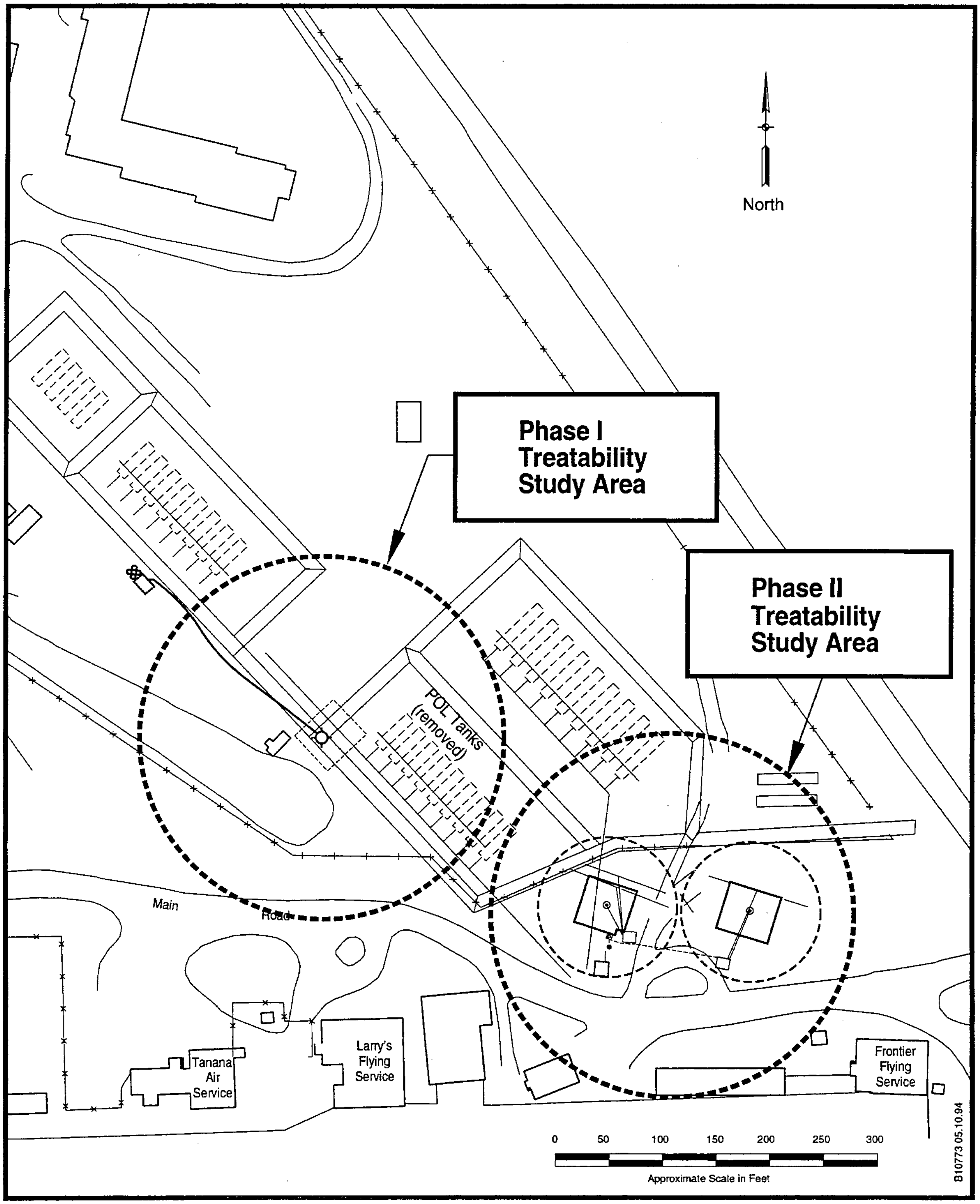


Figure 2-2. Location of the Treatability Study in the POL Tank Farm at Galena Airport

isopropanol used for runway deicing also remain at the site. Historically, tank trucks or buried transfer lines were used to carry fuels from the barge loading area on the east end of the airport to the POL Tank Farm. Aboveground distribution lines were then used to distribute fuels from the tanks to several fill stands.

The water level at the POL Tank Farm fluctuates by approximately 20 ft on a seasonal cycle in response to changes in the stage of the Yukon River. Groundwater flow is predominantly southwest toward the river at velocities from approximately 1 to 11 ft per day (USAF, 1993a). The gradient is about 1 ft vertical drop in 3500-ft horizontal distance (0.0003 ft/ft). Groundwater flow during the river flood stage is west to north, away from the river, at a rate of 1 to 5 ft per day (USAF, 1993a). The seasonal reverse flow to the north is of relatively short duration (less than one month). Flow reversals also occur briefly in response to river level increases during periods of high rainfall.

Contamination at the POL Tank Farm site is petroleum in nature and is found in both the subsurface soils and groundwater. The source of contamination is unknown but may be caused by leaking pipe fittings on the tanks or underground piping in the POL Tank Farm area, which was in operation for approximately 30 years.

Floating free product (LNAPL) was found in several monitor wells in the southern portion of the POL Tank Farm. The seasonal rise and fall of the water table has produced a "smear zone" of contaminated soil between approximately 8 and 30 ft bgl. Soils in this zone are inundated by a floating LNAPL layer during each seasonal groundwater cycle so that they become resaturated with hydrocarbons each spring. The LNAPL also contributes significantly to the dissolved-phase hydrocarbon levels in the groundwater.

2.2 Treatability Study Program

The TS program for Galena Airport was performed in two phases. Phase I included a pilot-scale test for SVE and a bench-scale biotreatability study. Phase II consisted of a pilot-scale test for enhanced SVE systems using air sparging and steam injection.

Figure 2-3 presents a chronology of the TS program for Galena Airport. The Phase I pilot-scale test and bench-scale test were conducted during the summer of 1992 and from late 1992 through early 1993, respectively. The Phase II pilot-scale test was conducted from the summer of 1993 through February 1994. The major activities associated with each test are presented below.

2.2.1 Phase I
Pilot-Scale Test

The Phase I pilot-scale test was conducted over a two-month period to evaluate the effectiveness of SVE at the POL Tank Farm. SVE is a proven and effective technique for removing VOCs from soils in the unsaturated (vadose) zone. The SVE system applies a vacuum to the subsurface vadose zone that induces air flow through the soil toward a vapor extraction well. The volatile hydrocarbons are physically removed from the soil into the air stream, and the replacement of soil gas by oxygen from the atmosphere enhances biodegradation of the organic contaminants. The specific objectives of the Phase I pilot-scale test were to:

- Determine whether SVE is a feasible technology for remediation at the POL Tank Farm site;
- Develop preliminary design criteria for expanded pilot-scale or full-scale remediation activities; and
- Identify possible environmental or operating constraints for the application of this technology at Galena Airport.

The SVE system consisted of a single vapor extraction well, a 6-hp Gast regenerative (rotary) vacuum blower, granular activated carbon (GAC) drums to control hydrocarbon emissions, and nested vapor probes. Soil gas and soil samples were collected periodically to determine the hydrocarbon removal rate and the residual soil contaminant levels after treatment. Process parameters were monitored and adjusted to achieve optimal performance of the SVE system.

Task Name	Start	End
Galena Treatability Study	24/Jul/92	26/Jan/95
Phase I Pilot-Scale Test	24/Jul/92	01/Oct/92
Final Work Plan Submittal	24/Jul/92	24/Jul/92
System Installation	27/Jul/92	30/Jul/92
System Startup	01/Aug/92	01/Aug/92
System Operation	03/Aug/92	25/Sep/92
Monitoring	30/Jul/92	01/Oct/92
Initial (soil and gas)	30/Jul/92	30/Jul/92
Day 5 (gas)	04/Aug/92	04/Aug/92
Day 20 (gas)	21/Aug/92	21/Aug/92
Day 25 (soil and gas)	26/Aug/92	26/Aug/92
Day 35 (gas)	07/Sep/92	07/Sep/92
Day 60 (gas)	29/Sep/92	29/Sep/92
Final (soil and gas)	01/Oct/92	01/Oct/92
Phase I Bench-Scale Test	15/Oct/92	12/May/93
Draft Work Plan Submittal	15/Oct/92	15/Oct/92
Final Work Plan Submittal	15/Jan/93	15/Jan/93
Samples Recieved	19/Oct/92	19/Oct/92
Study Preparation	19/Oct/92	07/Dec/92
Bench-Scale Test	08/Dec/92	03/Mar/93
Monitoring	21/Oct/92	15/Mar/93
Initial	21/Oct/92	21/Oct/92
Day 64	10/Feb/93	10/Feb/93
Day 97	15/Mar/93	15/Mar/93
TS ITI Report	12/May/93	12/May/93
Phase II Pilot Scale Test	15/Sep/92	26/Jan/95
System Design	28/May/93	24/Jun/93
Equipment/Shipping Coord	21/Jun/93	05/Jul/93
System Installation	06/Jul/93	01/Aug/93
System Startup	02/Aug/93	02/Aug/93
System Operation	02/Aug/93	10/Feb/94
Monitoring	29/Jul/93	10/Feb/94
Initial	29/Jul/93	03/Aug/93
Day 5 (gas only)	06/Aug/93	09/Aug/93
Day 15 (gas only)	19/Aug/93	22/Aug/93
Day 30	01/Sep/93	05/Sep/93
Day 60	01/Oct/93	05/Oct/93
Day 90	01/Nov/93	05/Nov/93
Day 120	06/Dec/93	10/Dec/93
Day 150	06/Jan/94	10/Jan/94
Day 180	05/Feb/94	10/Feb/94
Product Recovery Tests	15/Sep/92	22/Apr/94
Phase I	15/Sep/92	30/Sep/92
Phase II	15/Jul/93	01/Aug/93
Phase III	07/Apr/94	22/Apr/94
Reporting	30/Oct/93	26/Jan/95
Progress Reports	30/Oct/93	03/Apr/94
October	30/Oct/93	02/Nov/93
November	30/Nov/93	03/Dec/93
December	30/Dec/93	02/Jan/94
January	30/Jan/94	02/Feb/94
February	28/Feb/94	04/Mar/94
March	30/Mar/94	03/Apr/94
Draft TS Report	12/May/94	12/May/94
Final TS Report	26/Jan/95	26/Jan/95

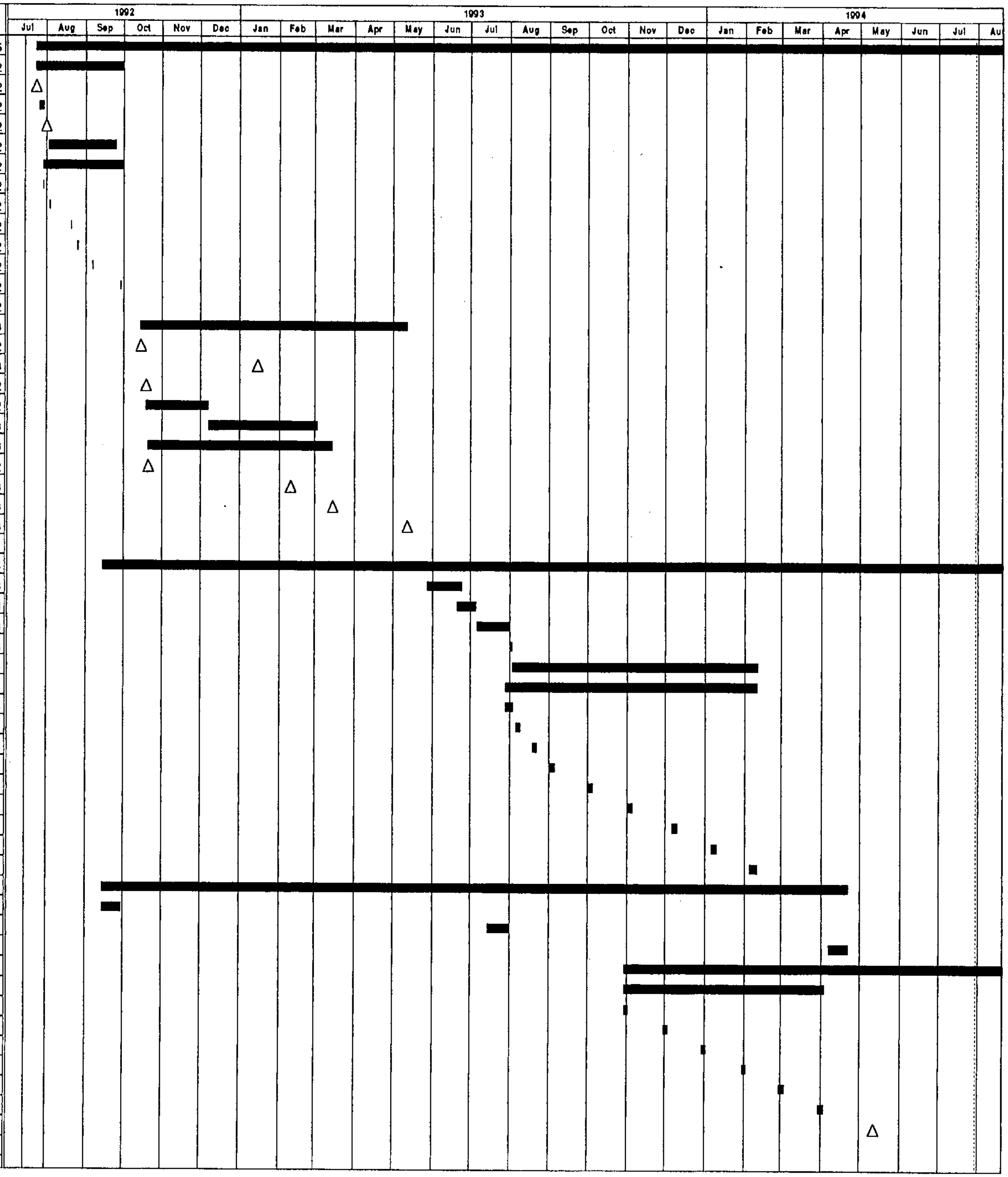


Figure 2-3. Chronology of the Treatability Study at Galena Airport

Bench-Scale Test

The bench-scale test was performed to evaluate the biotreatability of contaminated vadose-zone soils from the POL Tank Farm under simulated field conditions. The specific objectives of the bench-scale study were to:

- Characterize soils from the POL Tank Farm for contaminant levels, nutrients, and microorganism populations;
- Determine if microorganisms present in the soil could degrade hydrocarbon contaminants under simulated field conditions;
- Determine if chemical or biological enhancements would accelerate biodegradation; and
- Provide recommendations for possible pilot-scale biological treatment systems.

The bench-scale test design included several soil treatment conditions, including oxygen content, nutrient addition, moisture content, and inoculation with a commercial microbial consortium. Because of the subarctic conditions in central Alaska, all treatments were incubated around 4°C to simulate subsurface conditions. The study was conducted over a 97-day period with measurements of hydrocarbon contaminants at the beginning and end of the test. Soil respirometry was used to measure oxygen uptake and carbon dioxide evolution over a 65-day period. These data were used to calculate hydrocarbon degradation rates based on the stoichiometric oxidation of heptane.

2.2.2 Phase II

Pilot-Scale Test

Results of the Phase I studies were used to enhance the treatment design for Phase II. The Phase II pilot-scale test was conducted to evaluate the effectiveness of an enhanced SVE system for the treatment of the unsaturated-zone soils and contaminated groundwater at the POL Tank Farm. The enhanced SVE system included the in situ treatment of groundwater by air sparging and steam injection.

Air sparging involves the injection of air below the water table. As the air travels through the groundwater, volatile contaminants are stripped from the dissolved phase and from adsorption sites within the aquifer into the gas phase. Through the extraction well, the SVE system captures the contaminants when they reach the vadose zone. Air sparging and SVE have the added effect of providing oxygen to the subsurface, enhancing biodegradation of the contaminants.

Steam injection involves the addition of steam below the water table to increase the groundwater and vadose-zone temperatures. This effect should enhance both biodegradation and volatilization of the contaminants.

The specific objectives for the Phase II pilot-scale test were to:

- Compare the benefits and refine operating parameters for SVE operated with air sparging alone and with both air sparging and steam injection;
- Evaluate the feasibility of year-round operation of a remedial treatment system at Galena;
- Further refine optimal process design and operating parameters of the SVE system;
- Determine the spatial influence of the SVE, air sparging, and steam injection wells;
- Estimate the hydrocarbon removal rate by both physical and biological processes and to estimate the treatment time for cleanup of the POL Tank Farm; and
- Develop a conceptual design for a full-scale remediation system at the POL Tank Farm site using the data collected during the TS and remedial investigation.

The Phase II test was conducted in two adjacent study areas (test cells), each equipped with a central vapor extraction well and a network of soil vapor monitor probes, groundwater monitor wells, and soil sampling locations. The East Cell incorporated air sparging points upgradient to the direction of groundwater flow of the SVE well; the West Cell was similar but also contained steam injection points upgradient of the air sparging wells. The test was conducted over a six-month period from August to February. The contaminant concentrations in the soil gas, SVE exhaust, groundwater, and soils were monitored periodically during the test. These data were used to determine hydrocarbon removal rates. Performance tests, such as in situ respiration, air permeability, and zone of influence tests, were conducted to evaluate the effectiveness of the treatment systems further.

Section 3
PHASE I ACTIVITIES AND RESULTS

Phase I of the TS included both pilot-scale and bench-scale tests. These tests were designed to determine the feasibility of using SVE and in situ bioremediation techniques to remedy the hydrocarbon contamination at the POL Tank Farm as well as other sites at Galena Airport. The following discussion addresses the activities and results of the Phase I tests. These results were previously presented in an informal technical information report (USAF, 1993b).

3.1 Pilot-Scale Test

A Phase I pilot-scale test was conducted at Galena Airport from late July through early October 1992. Additional information on the test is contained in the *Pilot-Scale Treatability Study Work Plan* (USAF, 1992b). The site layout for the Phase I study, including the location of the monitoring network, is presented in Figure 3-1. The original test site was planned for the area northwest of the location shown in this figure. However, contamination was not present at the first location. As a consequence, a suitable power source was not available near the test area, and 150 ft of 2-in. PVC tubing was added to connect the blower from its planned location to the new test site.

Soil gas probes were installed in five locations at three depths (5, 10, and 15 ft below the original ground surface). Figure 3-2 presents a geologic cross section within the study area that shows the installation of those probes. Soil samples were collected at each vapor probe location for analysis of chemical, physical, and microbiological properties. A 6-in. extraction well was installed to 25 ft below original grade (the berm height was 4 to 5 ft). Three 2-in. inlet wells were also installed within the study area. Appendix A.1 contains the well construction diagrams for the Phase I test.

Startup of the SVE system occurred on August 1, and the system was operated almost continuously from August 1 to September 26, except when shut down for periodic maintenance or for sampling and testing of the system.

3.1.1 Monitoring and Testing

Table 3-1 presents the monitoring schedule for the Phase I pilot-scale test. Soil gas, system exhaust gas, and soil samples were collected during the test to measure the remediation effectiveness of the pilot-scale system.

Gas Sampling

Soil gas samples from the vapor probes were collected on five occasions using stainless steel vacuum canisters. Figure 3-3 presents the total non-methane hydrocarbons (TNMHC) and total BTEX (benzene, toluene, ethylbenzene, and xylenes) concentrations in the soil gas during the pilot-scale test. Appendix A.2 contains a summary of the analytical results. These concentrations generally decreased over time at probe V1, which is the closest monitoring point to the extraction well. The deep probes were only sampled once because the water table remained above the deep probes during the first four sampling events. The levels of VOCs at the deep probes (15 ft below original grade) were higher than concentrations measured at the shallower depths. The VOC concentrations remained relatively constant at the other two probes (V2 and V3) during the test period. Because of the presence of a free-product layer that served as a continuing source of hydrocarbons, the VOC concentrations did not decrease over time as expected for an SVE process. VOC contaminants in the free-product phase may have partitioned into the unsaturated zone under the induced vacuum.

Gas samples were also collected from the extraction well to characterize the SVE exhaust gas. The TNMHC and total BTEX concentrations in the extracted soil vapors decreased nearly two orders of magnitude during the two months of operation, as shown in Figure 3-4. The ratio of TNMHC to total BTEX remained relatively constant at approximately 13:1. The initial increase in exhaust gas concentrations was expected as the SVE system began to pull soil gas towards the extraction well. VOC concentrations dropped substantially between August 4 and August

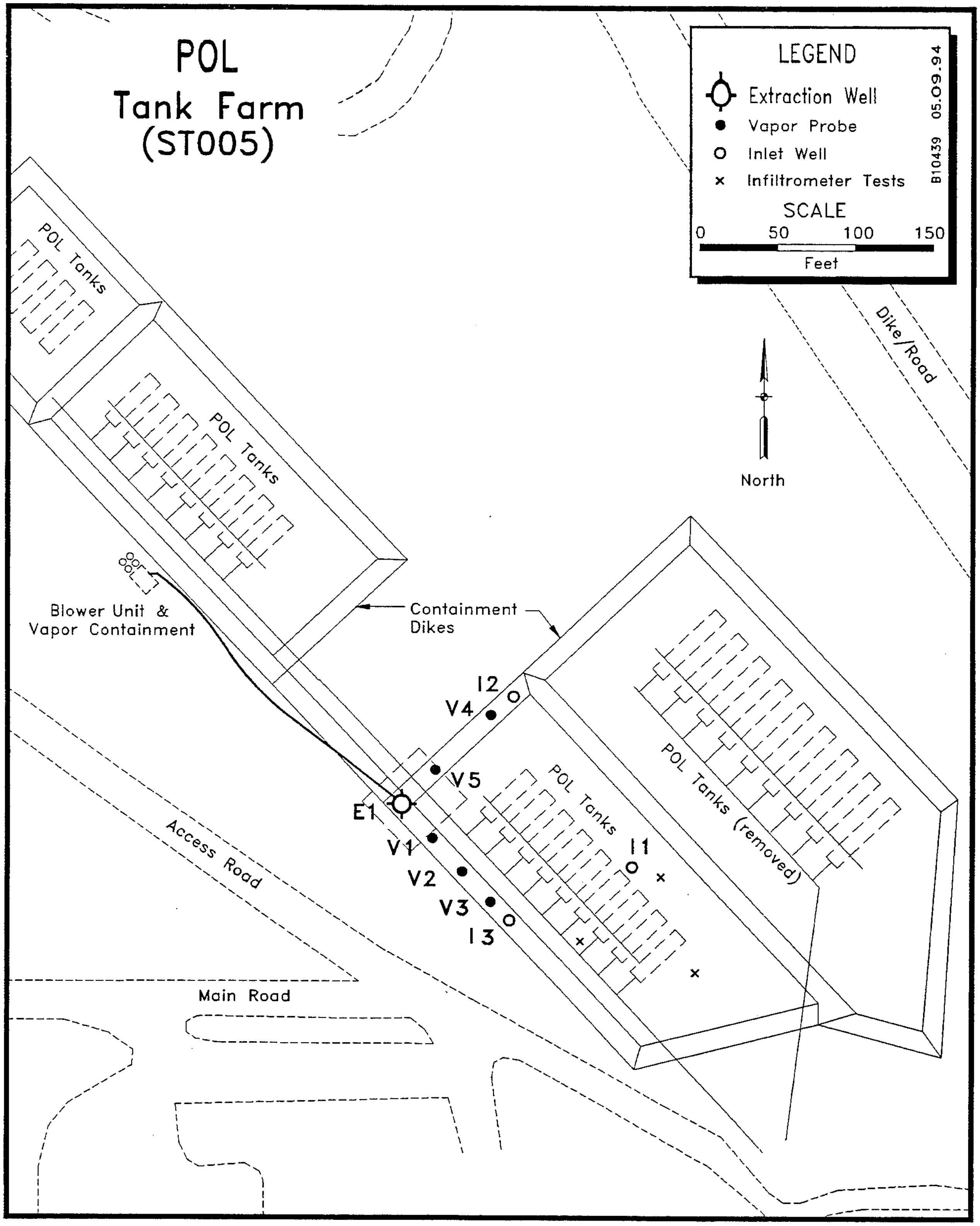


Figure 3-1. Layout of the Phase I Pilot-Scale SVE System

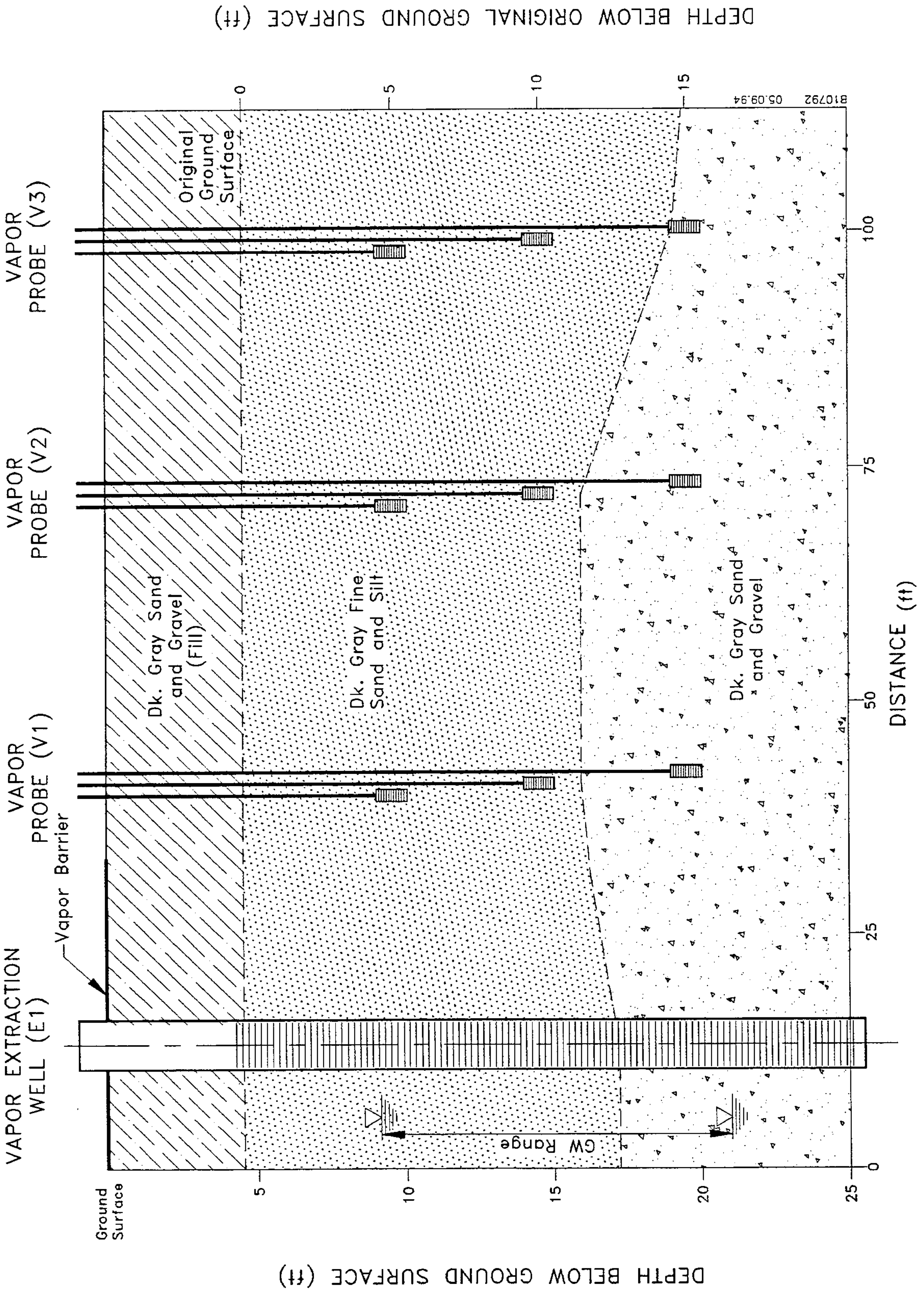


Figure 3-2. Cross Section Along the Berm in the Southeast Part of the POL Tank Farm

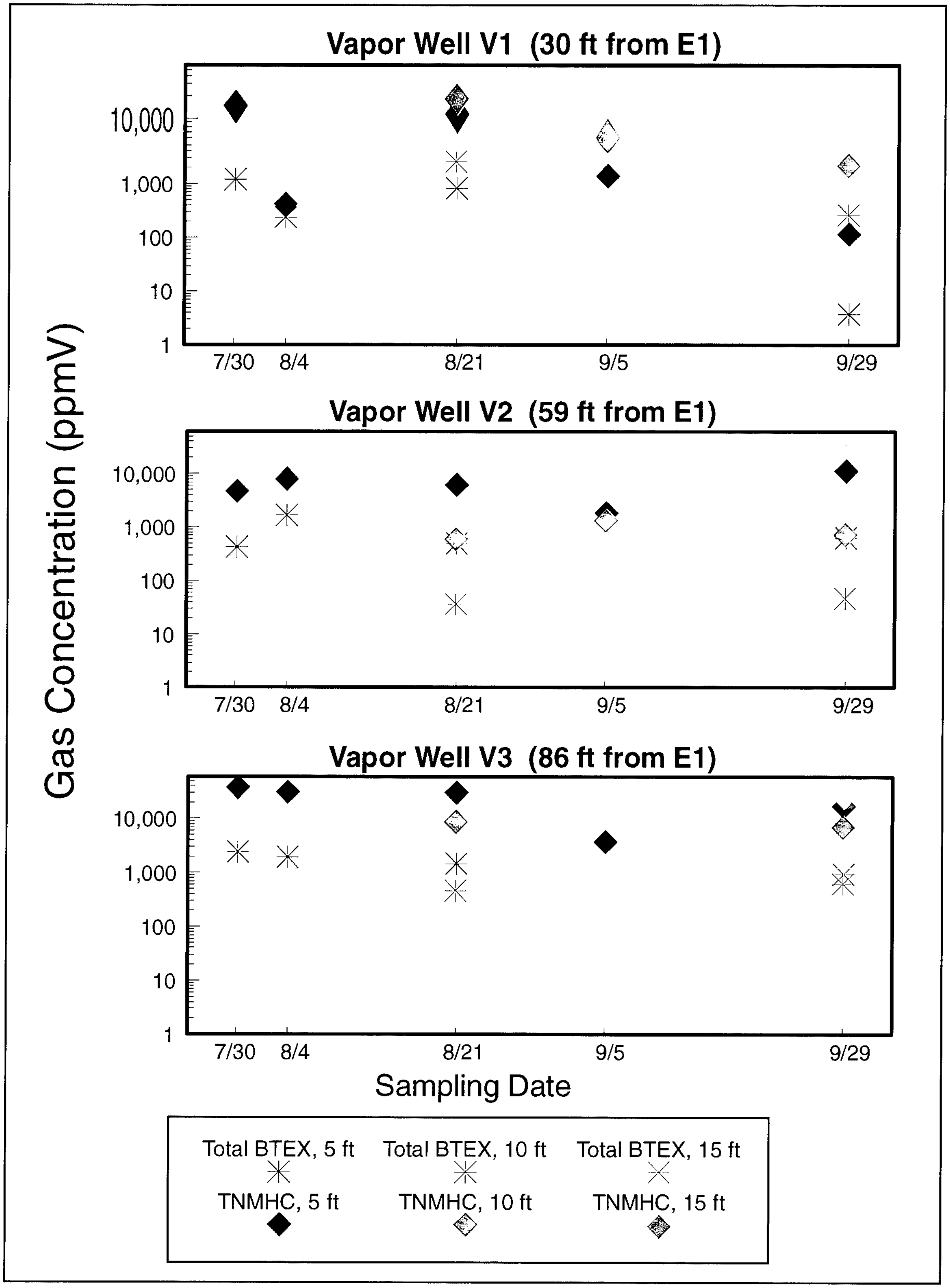


Figure 3-3. Concentrations of Total Non-Methane Hydrocarbons and BTEX Compounds in Soil Gas Samples Collected During the Phase I Pilot-Scale Test

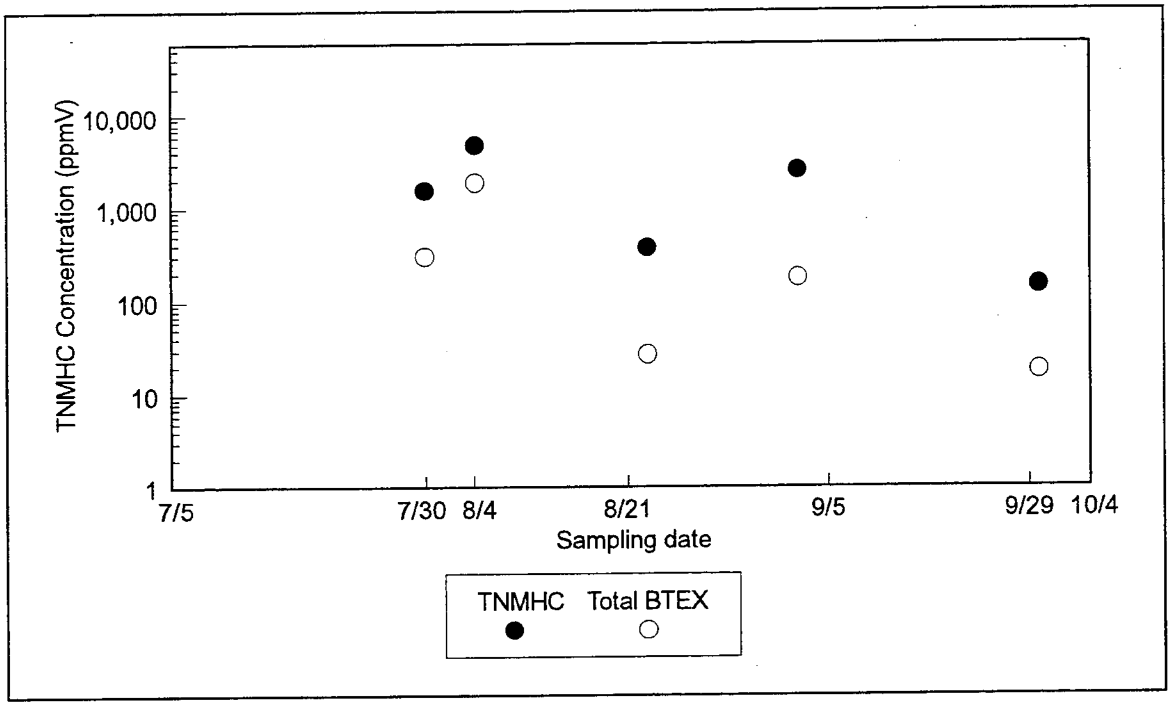


Figure 3-4. Concentration of Total Non-Methane Hydrocarbons (TNMHC) and Total BTEX Compounds in the Extracted Soil Gas During the Phase I Piolt-Scale Test

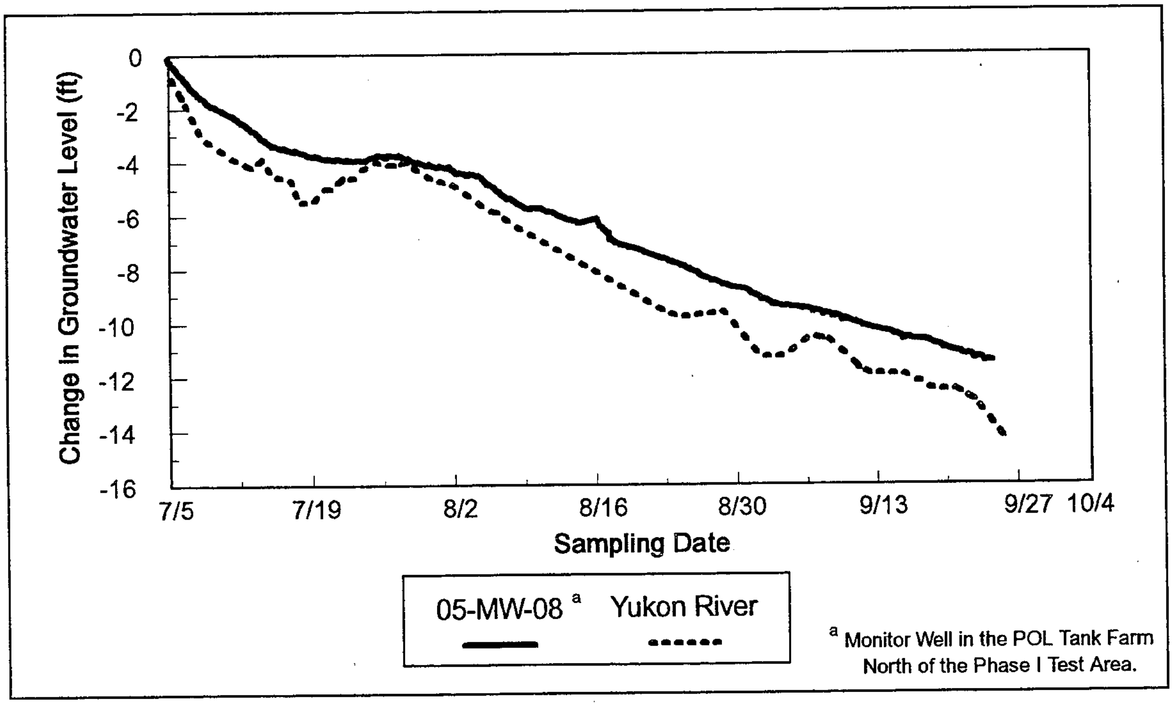


Figure 3-5. Water Level Change for the Yukon River and Monitor Well 05-MW-08 During the Phase I Pilot-Scale Test

Table 3-1
Sampling Schedule for the Phase I Pilot-Scale Test

Event [a]	Sampling Date	Matrix	Sampling Locations	Number of Samples	Analytes
G1	30 Jul 92	Gas	V1-V5, E1	7	TNMHC, BTEX
G2	4 Aug 92	Gas	V1, V2, V3, E1	4	TNMHC, BTEX
G3	21 Aug 92	Gas	V1-V5, E1, EX	13	TNMHC, BTEX
G4	5 Sep 92	Gas	V1-V5, E1	12	TNMHC
			E1	2	BTEX
G5	29 Sep 92	Gas	V1-V5, E1	17	TNMHC, BTEX
S1	25 Jul 92	Soil	V1-V5	17	BTEX, TPH, Moisture, pH, EC, NO_3^-, NH_4^+, PO_4^{-3}, TOC, PSD
S2	31 Aug 92	Soil	V1-V5	16	BTEX, TPH, pH
S3	30 Sep 92	Soil	V1-V5	17	BTEX, TPH

[a] G denotes gas sampling event; S denotes soil sampling event. EX = Exhaust gas after GAC units.

21, increased again on September 5, and then decreased for the final sampling event.

Variations in the vapor concentrations were probably a response caused by the hydrologic changes. The fluctuations of the water table and the Yukon River levels are shown in Figure 3-5. The groundwater and river levels decreased sharply in early and mid-July and again from August through September. The dewatering of the subsurface sand and gravel caused an increase in the soil porosity available for transmitting vapor flow. Before this dewatering, only the more dense silty soil was unsaturated, which had lower air permeability. Also as the water table declined, the zone of influence of the extraction well increased so that additional hydrocarbons were continually being pulled towards the well. The final decline in TNMHC and BTEX may have been due to a gradual diminishing of the contaminant source as the SVE system removed contaminants.

Soil Sampling

Soil samples were collected in the vicinity of the vapor probes on three occasions. The first soil sampling event was conducted before startup of the SVE system; the second and third events were conducted approximately one and two months after startup, respectively. Figure 3-6 presents the hydrocarbon concentrations in the soil samples collected near vapor probes V1, V2, and V3 during the study period. Concentrations of TPH, BTEX, and various fuel fractions in the soils were relatively low, typically below 10 mg/kg. In general, there was a slight decrease in hydrocarbons between the first and second sampling events, followed by an increase in the third sampling event. The analytical results are summarized in Appendix A.2.

Although the SVE system was expected to decrease the hydrocarbon concentrations in the soils during the treatment period, there are several factors that may explain the observed trend:

- Hydrocarbon Smear Zone—Hydrocarbons are adsorbed to soil particles within a broad smear zone that encompasses the entire range of water table fluctuations.
- Hydrologic Effects—The declining water table exposed fresh reserves of VOCs, which could have been drawn upward into the unsaturated zone by the SVE system. This is the most plausible explanation for increases in both the soil and soil gas hydrocarbon levels in September.
- Contaminant Variability—Although the soil samples from all three events were collected in the same hole, local soil heterogeneity in

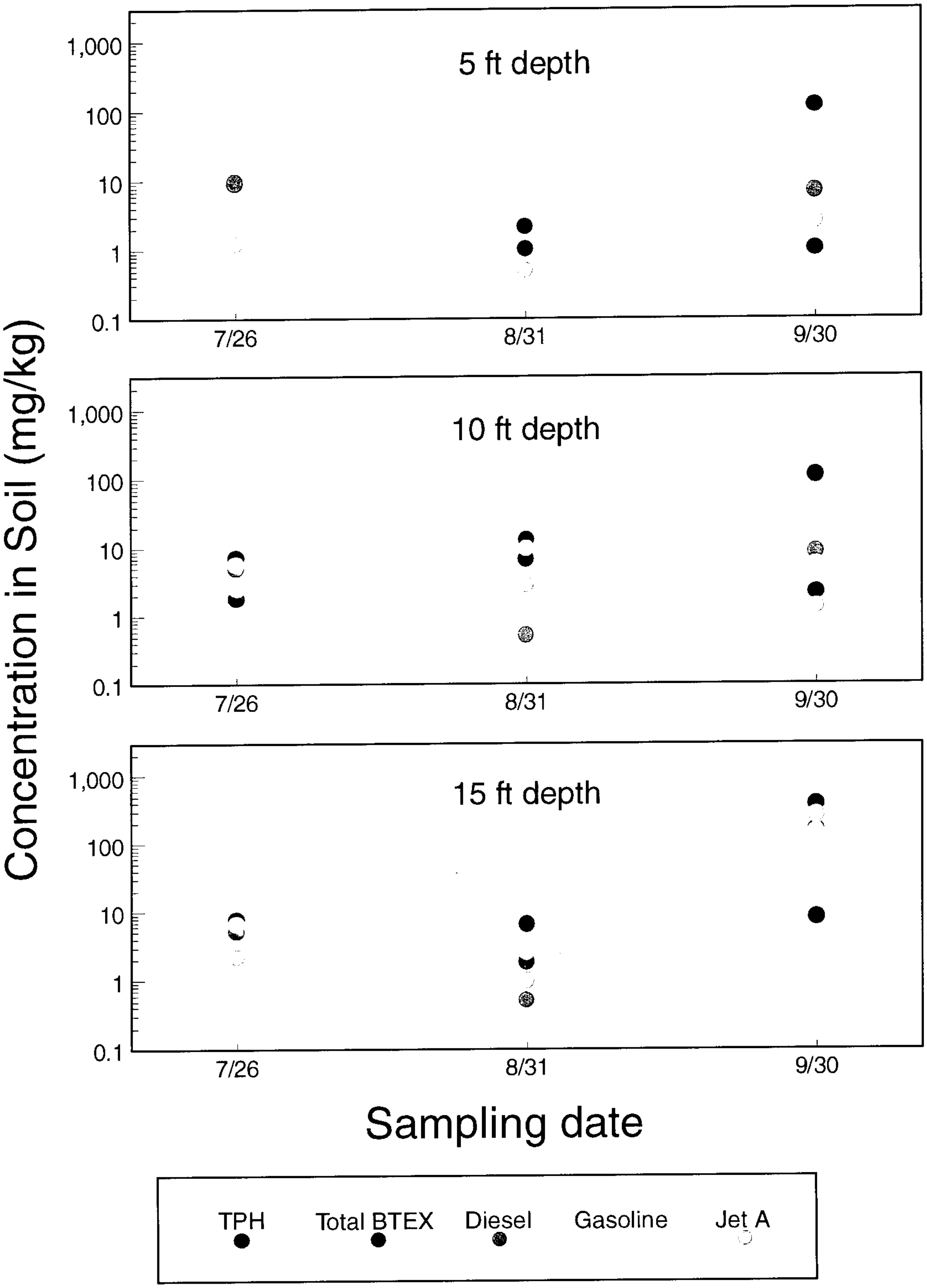


Figure 3-6. Concentrations of Hydrocarbons in Soil Samples from Locations V1 - V3

the horizontal plane may account for some of the observed differences in sample concentrations.

- LNAPL Lenses—Zones of floating free LNAPL were identified in a groundwater well located near the TS pilot-scale test site. The distribution of LNAPL in the POL area is not completely understood.
- Hydrocarbon Partioning—Volatile components present in the intermittent LNAPL lenses and dissolved in groundwater provided a continuing source for VOCs extracted by the SVE system.

Air Permeability and Zone of Influence

An air permeability test was conducted immediately after startup of the SVE system. However, site conditions (e.g., water table lingering in the silty upper strata) prevented an accurate determination of the air permeability at that time. A second air permeability test was performed after the water table had dropped below the depth of the 10-ft vapor probes. This test was conducted by shutting off the system and allowing the study area to return to a natural pressure condition. The SVE was then restarted and the transient pressures were monitored in each vapor probe until they stabilized. This transient pressure data were later evaluated by using a gas flow model by Johnson, Kemblowski, and Colthart (1990) to estimate the air permeability.

Figure 3-7 presents an idealized flow net for the pilot-scale SVE system on the basis of observations and data collected during the second air permeability test. From mathematical modeling, the radius of influence was as much as 110 ft. However, field observations suggest that the "effective" radius of influence was approximately 60 ft. The model does not account for certain site conditions (e.g., the vapor barrier and the high water table), so the air permeability of the soils and therefore the radius of influence were overestimated. Appendix A.3 contains the test data and an example calculation of air permeability.

Infiltration Tests

In early August, infiltration tests were conducted at three locations in the southern portion of the POL Tank Farm area (refer to Figure 3-1) using a tension infiltrometer. At each location, the top 9 in. of fill soil was removed to expose the underlying native sediments (these tests were not performed on the berm). At each location, the soils consisted of dark grayish brown silty alluvium. The tests were conducted to characterize the hydraulic properties of the unsaturated-zone soils.

Results of these tests were used to calculate unsaturated hydraulic conductivity as a function of matrix potential for the vadose zone soils at each of the test locations. The estimated saturated hydraulic conductivity (i.e., at zero matrix potential) for the soils ranged from 3.9×10^{-5} to 8.8×10^{-4} cm/sec. These data would be useful if it is determined that an irrigation system is needed to deliver moisture and nutrients to subsurface soils. Appendix A.4 contains the infiltration data, hydraulic conductivity curves, and the calculation of irrigation requirements.

3.1.2 Unit Operation

The system was operated almost continuously during the test period, except for scheduled shutdowns for maintenance and sampling events. On September 26, condensation in the vacuum hose from the extraction well froze and caused the SVE blower unit to shut off. During the previous week, ambient temperatures had fallen dramatically to below 5°F at night and remained below freezing nearly continuously during the day. Because the pilot-scale system components were not insulated or otherwise weatherized to allow for winter operation, the system was not restarted. A final set of soil and soil gas samples was collected on September 30 to complete the Phase I test.

A test was conducted to evaluate the effect of the inlet vacuum on exhaust gas flow rate. Flow rates were estimated from the inlet vacuum, backpressure, differential pressure at the inlet manifold, atmospheric pressure, and temperature using the manufacturer's differential pressure guage rating curves. The test results indicated that the maximum air flow (about 82 scfm at the wellhead occurred at vacuums from 65 to 74 in. H_2O. The flow decreased at higher vacuums, possibly as a result of upwelling of groundwater into the extraction well that decreased the effective screen length of the well.

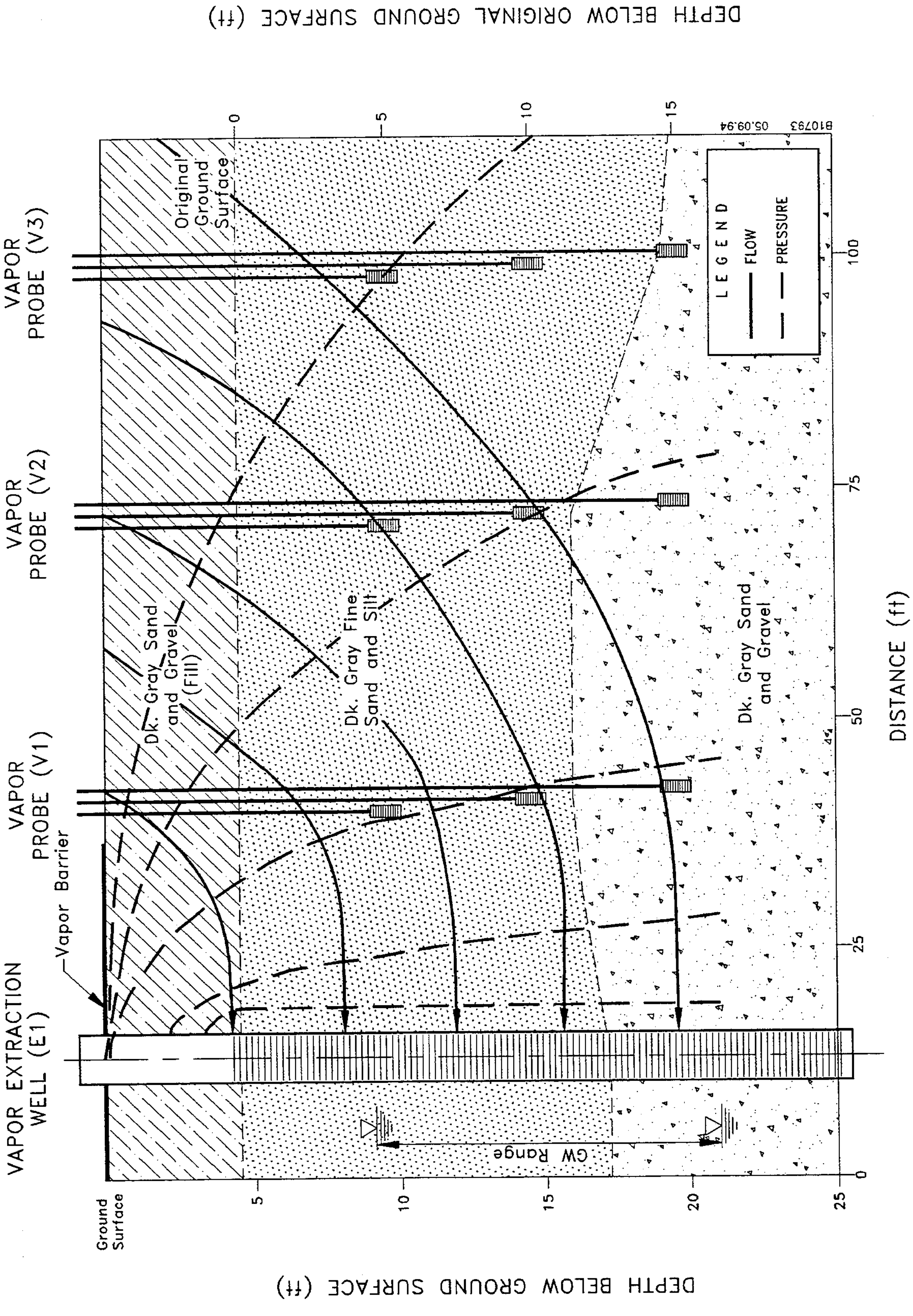


Figure 3-7. Idealized Air Flow Diagram Based on Observations During the Phase I Pilot-Scale Test

Four 55-gal. drums of GAC were used to capture VOC emissions from the SVE blower unit. Initially, the exhaust from the blower was split and run through two parallel GAC drums. VOC levels were measured daily using an organic vapor monitor. A gradual breakthrough of VOCs from the drums was observed beginning on August 5, when measured concentrations (total VOCs as benzene) ranged from 20 to 40 ppm. Measured VOC concentrations gradually increased to 130 ppm over the next week. On August 10, a second set of GAC drums was connected in series (downstream) with the original drums. Concentrations fell to < 4 ppm but, again, gradually increased over the following week. By August 19, concentrations had reached 100 to 130 ppm again.

The observed rate of VOC breakthrough was faster than anticipated, based on preliminary estimates provided by Calgon Corporation (the vendor for the GAC drums). On August 28, the existing GAC canisters were replaced by four new drums connected in parallel and in series as before. VOC emissions dropped to < 5 ppm. On September 10, VOC emissions were once again in the range of 150 to 200 ppm and remained in that range until system shutdown on September 26.

3.1.3 Results of Phase I Pilot-Scale Test Hydrocarbon Removal

It is estimated that the SVE system removed 3200 lb of VOCs from the contaminated zone beneath the POL Tank Farm during the two-month operating period, as shown in Figure 3-8. The mass of VOCs removed was estimated using TNMHC concentrations at the extraction well along with measurements of vapor flow through the system. Details on the calculation of estimated cumulative hydrocarbons removed are presented in Appendix A.5.

A mass balance was performed for hydrocarbons present in the unsaturated-zone soils, assuming a 60-ft radius of influence and a 15-ft depth and using the average soil concentration for each 5-ft sampling interval from the initial sampling event (see Appendix A.5). The estimated mass of initial hydrocarbons present was less than the estimated mass of hydrocarbons removed by the SVE system (see Figure 3-8). The most probable source of the additional mass of hydrocarbons removed is the groundwater beneath the POL Tank Farm. Floating free-phase hydrocarbons may have partitioned into the unsaturated zone.

Vapor Emission Control

Performance data collected during the Phase I pilot-scale test indicated that GAC is not a cost-effective means of emission control. Concentrations in the SVE exhaust did not decline with time as originally anticipated, causing the sorption capacity of the GAC units to be exceeded rather quickly (7 to 10 days). Other emission control techniques, such as internal combustion engines, catalytic or thermal oxidation units, condensers, biofilters, flares, and venting through elevated stacks, should be considered for a full-scale remediation system.

3.2 Bench-Scale Test

Bench-scale testing was conducted from late October 1992 through March 1993. The bench-scale test involved a soil incubation study designed to evaluate the biotreatability of hydrocarbon-contaminated soils at Galena Airport. The seven soil treatment conditions evaluated during the test are presented in Table 3-2. The treatment conditions were selected to evaluate the merits of increased oxygen concentrations, water saturation, nutrient additions, and commercial bacterial inoculum additions for enhancing biodegradation of petroleum hydrocarbons.

Details of the experimental methods and procedures are contained in Appendix B.1. Additional information is also provided in the *Bench-Scale Treatability Study Work Plan* (USAF, 1993c). The bench-scale test involved an initial characterization of the soils to be treated, collection of oxygen uptake and carbon dioxide evolution data for the various treatment conditions, and final characterization of the residual contaminant levels in the soils after treatment.

3.2.1 Soil Characterization

Subsurface soil samples were collected from the POL Tank Farm site during the installation of the vapor probes for the Phase I pilot-scale test. The samples were composited for the bench-scale test, and

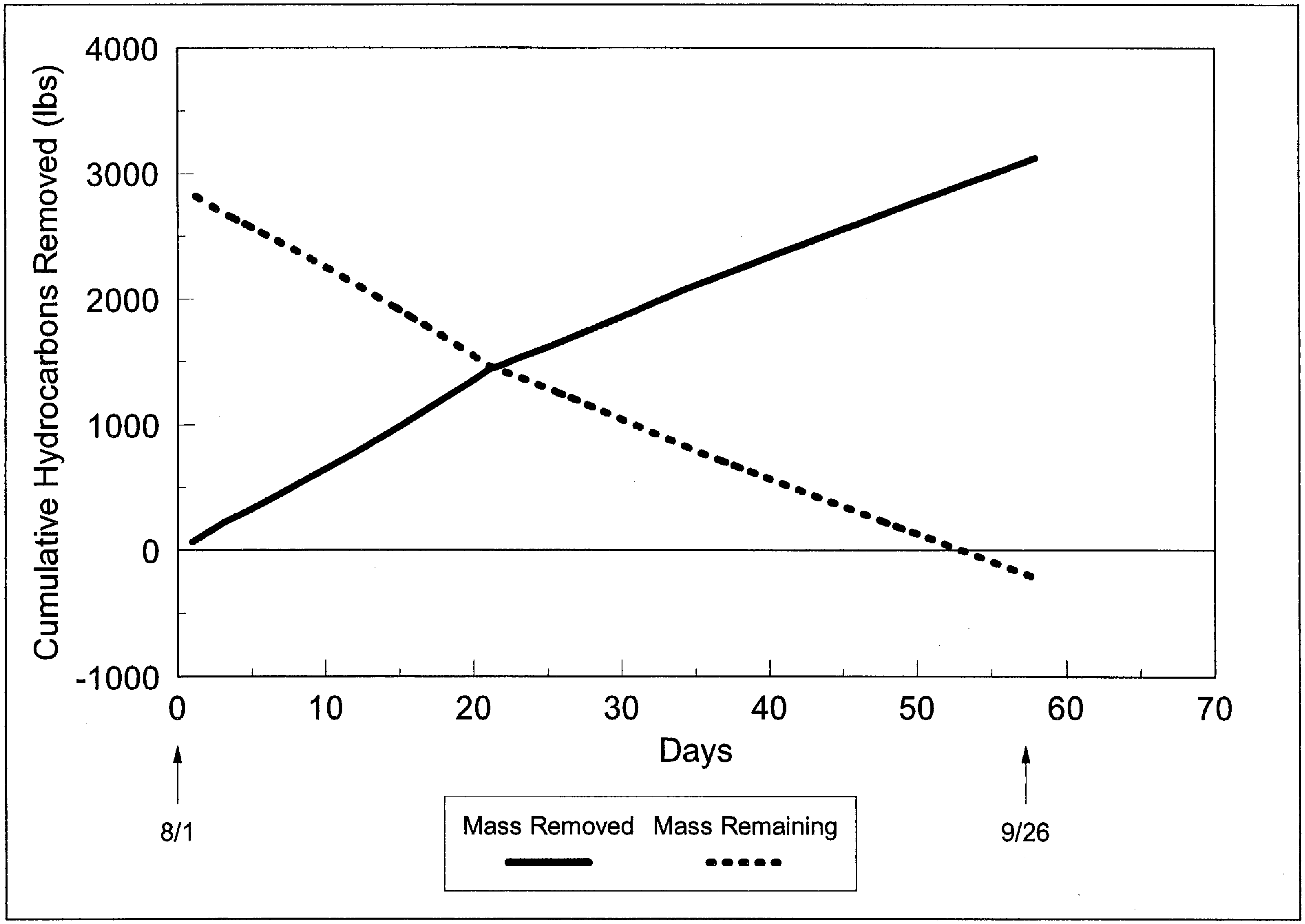


Figure 3-8. Hydrocarbon Removal at the POL Tank Farm During the Phase I Pilot-Scale Test

each composite sample was analyzed for target contaminants; nutrients; and selected soil physical, chemical, and microbiological parameters prior to the study and after the 60- and 97-day incubation periods. Table 3-3 presents the analytical methods and frequency of sampling for the study.

Table 3-4 presents the results of the analyses for the soils before and after the bench-scale study for each treatment condition tested. The average total petroleum hydrocarbons (TPH) concentration of the contaminated soil was 1055 mg/kg, which included 133 mg/kg of BTEX compounds. Nutrient levels were very low, with initial C:N and C:P ratios of approximately 2100:1 and 1100:1, respectively. The mildly alkaline (pH 7.7) sandy soil contained low levels of organic carbon (0.7%) and salts (according to the electrical conductivity of 0.49 mmho/cm). The numbers of total heterotrophic bacteria were relatively high, ranging from 10^6 to nearly 10^8 colony-forming units per gram (CFU/g); up to 2.6×10^6 CFU/g of the microbial population was hydrocarbon-utilizing bacteria. These analytical results are summarized in Appendix B.2.

3.2.2 Respirometry Tests

Biotreatability kinetics were measured for each treatment condition by determining the microbial respiration rates for the initial 60 days of the incubation period by using closed respirometer flasks. The tests were conducted at temperatures ranging from 2° to 5° C to simulate the subsurface conditions at Galena Airport. Oxygen uptake (consumption) and carbon dioxide evolution were measured over time to evaluate the biodegradability of the hydrocarbon contaminants.

3.2.3 Degradation Rate

Degradation rates of hydrocarbon contaminants for the seven treatment conditions were determined by two methods: 1) calculation of the TPH removed with time, on the basis of the initial and final soil analyses, and 2) estimation of hydrocarbon degradation rates using the oxygen uptake data and assuming the stoichiometric oxidation of heptane.

Table 3-5 summarizes the hydrocarbon degradation rates for each treatment condition. Appendix B.3 contains the procedures and example calculations used to determine the degradation rates.

All treatment conditions supported substantial degradation of TPH and BTEX contaminants. There was also relatively good agreement between the estimated hydrocarbon degradation rates, on the basis of oxygen consumption and the actual TPH removal rates calculated using initial and final TPH concentrations.

Low levels of oxygen or water saturation did not appear to inhibit microbial growth, respiration, or contaminant degradation. Nutrient addition did not increase respiration or contaminant degradation. Bioaugmentation did enhance the treatment of the contaminated soils, compared with the other treatment conditions, but not to a significantly greater degree than the unamended treatment conditions at 2% to 14% oxygen. From these results, bioremediation is feasible for hydrocarbon degradation in the soils at the POL Tank Farm.

Table 3-2
Experimental Design of the Galena Biotreatability Study

Treatment	Description
-	Barometric Control (glass microbeads)
1	Contaminated Soil, 21% O_2 (atmospheric) (Unamended Control)
2	Contaminated Soil, 14% O_2
3	Contaminated Soil, 7% O_2
4	Contaminated Soil, 2% O_2
5	Contaminated Soil + Nutrients, 21% O_2 (atmospheric)
6	Contaminated Soil + Water Saturation, 21% O_2 (atmospheric)
7	Contaminated Soil + Nutrients + Inoculum, 21% O_2 (atmospheric)

Table 3-3
Analytical Procedures, Estimated Detection Limits, and Frequency of Soil Analyses for the Bench-Scale Test

Parameter	Method	Detection Limit	Frequency or Sampling Time (days)
Particle Size Distribution	ASTM D422-63 [a]	NA	0
Percent Moisture	ASTM D2216	NA	Biweekly
pH	EPA SW-846 9045 [b]	NA	0, 60
Electrical Conductivity	EPA 600 120.1 [c]	0.005 mmhos/cm	0
Nitrate-Nitrogen	Am. Soc. Agro. 33-8.3 [d]	15 mg/kg	0
Ammonia-Nitrogen	Am. Soc. Agro. 33-7.3	5 mg/kg	0
Phosphate-Phosphorus	TAES STP 4-5 [e]	5 mg/kg	0
Total Organic Carbon	Am. Soc. Agro. Modified 29-2.2.4	0.1%	0
Total Petroleum Hydrocarbons (TPH)	EPA SW-846 8015 ME/MP	0.5 mg/kg	0
Aromatic Volatile Organics	EPA SW-846 8020	0.05 mg/kg	0, 60
Heterotrophic Organisms	Am. Soc. Agro. 37	300 cells/g	0, 60
Hydrocarbon-Utilizing Organisms	Am. Soc. Agro. 37	300 cells/g	0, 60
Carbon Dioxide Evolution	Acid-base Titration	NA	Weekly
Oxygen Uptake	Manometric	NA	Daily
Temperature	Mercury Thermometer	NA	Daily

Notes: [a] American Society for Testing and Materials. *Annual Book of ASTM Standards.* November 1987. [b] U.S. Environmental Protection Agency. *Test Methods for Evaluating Solid Waste.* Third Edition. SW-846, 1986. [c] U.S. Environmental Protection Agency. *Methods for Chemical Analysis of Water and Wastes.* EPA-600/4-79-020. March 1983. [d] American Society of Agronomy, Inc. *Methods of Soil Analysis, Part 2, Chemical and Microbiological Properties*, Second Edition, 1982. [e] Soil Testing Procedures. Texas Agriculture Extension Service.

Table 3-4
Physical and Chemical Characterization Results for the Soil Samples Before and After the Incubation Period

		Post-Treatment						
		Contaminated Soil No Amendments				Contaminated Soil, Sparged with 21% O_2 + Amendments		
Parameter	Pre-Treatment	21% O_2	14% O_2	7% O_2	2% O_2	Nutrients	Nutrients + Water Saturation	Inoculum + Nutrients
TPH[a], mg/kg	1,055	279.9	430.6	456.2	398.7	555.5	546.5	346.9
Benzene, mg/kg	7.62	<0.5	1.52	1.45	<0.5	<0.5	<0.5	<0.5
Toluene, mg/kg	46.75	1.32	2.12	2.03	2.56	14.83	7.33	6.51
Ethylbenzene, mg/kg	17.32	<0.5	<0.5	<0.5	<0.5	4.15	1.89	1.81
Xylenes, mg/kg	61.37	1.17	2.34	2.93	2.49	24.54	12.18	11.42
Heterotrophic Organisms, CFU[b]/g	10^6 to 10^8	$9.6\text{x}10^7$	$9.4\text{x}10^7$	$1.2\text{x}10^8$	$1.6\text{x}10^8$	$1.7\text{x}10^6$	$1.5\text{x}10^8$	$4.0\text{x}10^7$
Hydrocarbon-Utilizing Organisms, CFU[b]/g	$<2.6\text{x}10^6$	$5.6\text{x}10^5$	$6.9\text{x}10^3$	$1.1\text{x}10^3$	$3.8\text{x}10^3$	$5.3\text{x}10^5$	$1.5\text{x}10^6$	$>10^7$

Additional Parameters	Pre-Treatment
NH_4-N, mg/kg	3.45
NO_3-N, mg/kg	ND
PO_4-P, mg/kg	6.46
pH	7.68
Electrical Conductivity, mmho/cm	0.49
Moisture, %	26.4
Particle Size Distribution, %	
Sand	87.5
Silt	9.4
Clay	3.16

Notes: [a]TPH data based on 97 days of incubation, all other data reported based on 60 days. [b]CFU = colony forming units.

Table 3-5
Summary of Hydrocarbon Removal Rates from Bench-Scale Test

No.	Treatment	Oxygen Uptake Rate (mmol/kg/day)	Estimated Hydrocarbon Biodegradation Rate[a] (mg/kg/day)	% TPH Removed[b]	TPH Removal Rate[b] (mg/kg/day)
1	21% O_2	0.13	1.2	73	8.0
2	14% O_2	0.56	5.1	59	6.4
3	7% O_2	0.51	4.7	57	6.2
4	2% O_2	0.52	4.7	62	6.8
5	21% O_2 + nutrients	0.28	2.6	47	5.1
6	21% O_2 + nutrients + saturation	0.32	2.9	48	5.2
7	2% O_2 + inoculum + nutrients	0.63	5.7	67	7.3

Notes: [a] Estimates based on stoichiometric relationship between oxygen consumption and degradation of a representative hydrocarbon (heptane).
[b] Calculation based on chemical analysis for TPH in soil before and after treatment.

Section 4
PHASE II ACTIVITIES AND RESULTS

The Phase II pilot-scale test was conducted to further assess the treatment effectiveness of SVE and to evaluate the merits of air sparging and steam injection in combination with SVE at the POL Tank Farm site. The study was conducted from August 1993 through early February 1994.

The following discussion presents the activities associated with the Phase II pilot-scale test. The *Pilot-Scale Treatability Study: Phase II Work Plan* provides more detail on the analytical and test procedures used during the TS (USAF, 1993d). Monthly progress reports were prepared during the test; these reports contain more detail on the daily activities during the study.

Design activities for the TS began in late May 1993 and included the conceptual and detailed design of the process configuration, layout, and operating conditions; identification and sizing of the process components; solicitation of vendor information and quotes; purchase of equipment and materials; and coordination of the field activities. Support was provided by the 11 CEOS/CEVR for the following activities: providing electrical power to the site, moving heavy process equipment, site preparation and earthwork, drilling and installation of the wells, and providing general construction support.

4.1 System Installation

Construction and installation activities for the Phase II pilot-scale test were accomplished during July 1993. The initial site activities included obtaining utility clearances, moving equipment and materials to the site, clearing trees and brush, and moving vehicles parked on site. The locations of the drilling sites and equipment enclosures were then surveyed and staked. The installation of the monitoring network within the study area and construction and installation of the equipment and process components were accomplished during this period. This included the construction of two equipment enclosures and a drain field for the boiler blowdown; the installation of the piping, heat trace, and insulation for the SVE; air sparging; and steam injection systems, plumbing for the boiler water supply system, electrical wiring for the process equipment and enclosure lights, and the installation of vapor barriers around the extraction wells and a caution fence around the perimeter of the study area. The system installation was completed on August 1.

Figure 4-1 presents the site layout for the Phase II pilot-scale test, including vapor probes, monitor wells, soil sampling locations, extraction wells, air sparging points, and steam injection points. The treatment configuration in the West Cell included SVE, IAS, and steam injection systems; the treatment system in the East Cell used SVE and IAS systems (no steam injection). Figure 4-2 presents a schematic diagram of the major process components installed for the Phase II pilot-scale test.

Thirty-eight vapor probes (generally two depths at 20 locations) were installed with an electric rotary hammer to mechanically drive the vapor probes and tubing to the desired depth. The two vapor extraction wells, six monitor wells (two of the eight wells were existing monitor wells), 28 air sparging points (two depths at 14 locations), and 12 steam sparging points (two depths at six locations) were installed with a hollow-stem auger drill rig. Details of these wells are contained in Appendix C.1. Eleven 5-ft pilot holes and one 10-ft pilot hole (B-2 at the POL perimeter dike) were installed at the soil sampling locations with the drill rig so that soil samples could be collected during the winter sampling events without having to penetrate frozen soils. Pilot holes were covered with plywood boxes to prevent snow from accumulating in the holes.

4.2 System Startup and Operation

Each process was checked for proper operation before the startup of the treatment system. This included testing the motors for their direction of rotation, adjusting the controls on the boiler and feedwater system, testing the piping for leaks, and checking the operation of the mechanical equipment.

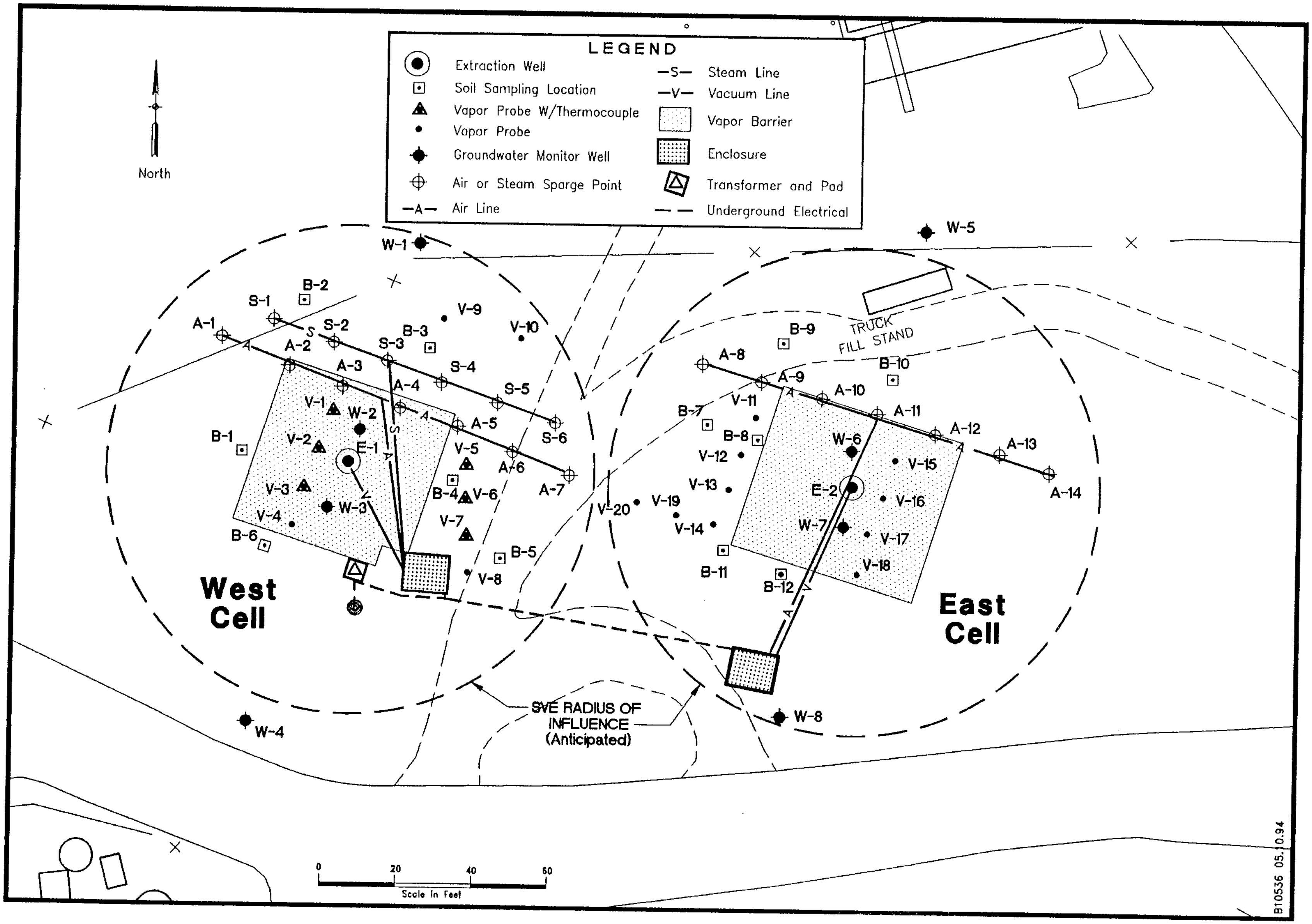


Figure 4-1. Site Layout for the Phase II Pilot-Scale Test

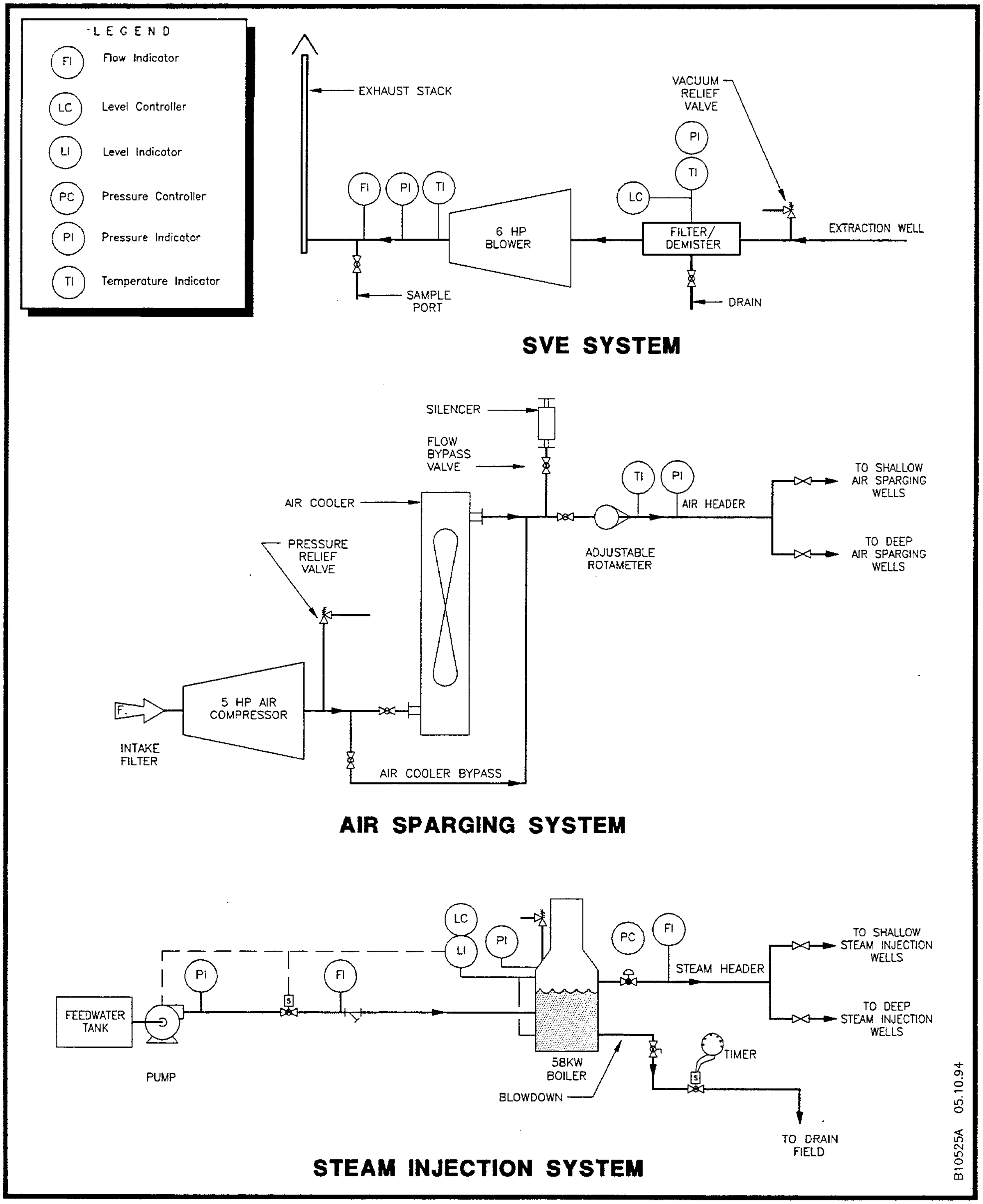


Figure 4-2. Schematic Diagram of the Process Components for the Phase II Pilot-Scale Test

4.2.1 West Cell Operation

The SVE, IAS, and steam injection systems were started on August 2. Figure 4-3 presents the daily hours of operation for each process component in the West Cell, as determined from daily monitoring logs and notes in the field logbooks. The figure also identifies disruptions in the system operation caused by intentional and unintentional shutdowns.

Power outages caused several intermittent shutdowns of the process equipment. After each outage, the equipment remained inoperable until the operator manually restarted the system. The SVE and IAS systems were also intentionally shut down during certain gas sampling and performance testing events to ensure the systems did not interfere with the monitoring results. Additionally, the West Cell SVE and IAS systems were shut down twice to perform maintenance on the boiler (October 28 and December 14). On October 9, a thermal sensor shut off the IAS system because of overheating. Overall, the SVE system was operational more than 92% of the test period, and the IAS system was operational for 94% of the test period.

The boiler operated regularly until the system failed at the end of November, when the corrosion of the heating elements caused an electrical short within the boiler. Previously, the steam injection system shut down a few times because of the lack of feedwater for the boiler (August 6 through 10, October 15, and November 13). The boiler feedwater was delivered to the boiler by a feed pump and a 300-gal. tank. The City of Galena delivered water to the site by truck. Initially the delivery service was inconsistent, so that occasionally the tank went dry, causing the boiler to shut down until water was delivered. Overall, the steam injection system was operational 55% of the test period.

On October 27, the boiler shut down because silt and lime sludge had accumulated in the boiler feed and blowdown lines despite the daily blowdown procedures. The sediment was fine enough to pass through the strainer in the feed line. On November 28, the boiler shut down again because of a malfunction of the heating elements. Silt and lime sludge had again built up in the piping and boiler water tank. The second outage emphasized that the quality of the water from the City of Galena was not compatible with the materials used to construct the boiler. New boiler components were ordered, but the problem of poor water quality and the unavailability of a boiler mechanic or electrician in Galena led to the decision to leave the boiler inoperable through the end of the pilot-scale test. The boiler was restarted a couple of times, and could be made fully operational once new heating elements and a water softener are installed.

4.2.2 East Cell Operation

In the East Cell, the SVE system was started on August 3, but the IAS system was not started until August 17 because of the breakage of an IAS system component during installation. The daily operation periods of the East SVE and IAS systems are shown in Figure 4-4. The previous discussion of the equipment shutdowns from power outages and for sampling events in Section 4.2.1 also applies to the process components in the East Cell.

Overall, the operation of the East SVE system was inconsistent during the first four months of the test; the system was operational 82% of the test period. During the first two months, the SVE was shutting down on a regular basis because of water collecting in the knockout tank. The SVE was designed so that when the knockout-tank capacity is reached (about 9 gal.), a float switch shuts off the system. Since the system requires a manual restart, it often remained off until the next day when daily process checks were performed. During October and November, the SVE system also shut down several times because of a thermal overload. In each case, the enclosure temperature had risen to above 100°F, which caused the SVE to shut down. The IAS system in the East Cell operated almost continuously throughout the test, with the exception of power outages and scheduled sampling events—approximately 90% of the test period.

4.3 Monitoring

The monitoring program for the Phase II pilot-scale test included initial and periodic sampling of soils, soil gas, groundwater, and SVE exhaust gas; daily operational checks on process parameters; and intermittent system performance testing. The daily

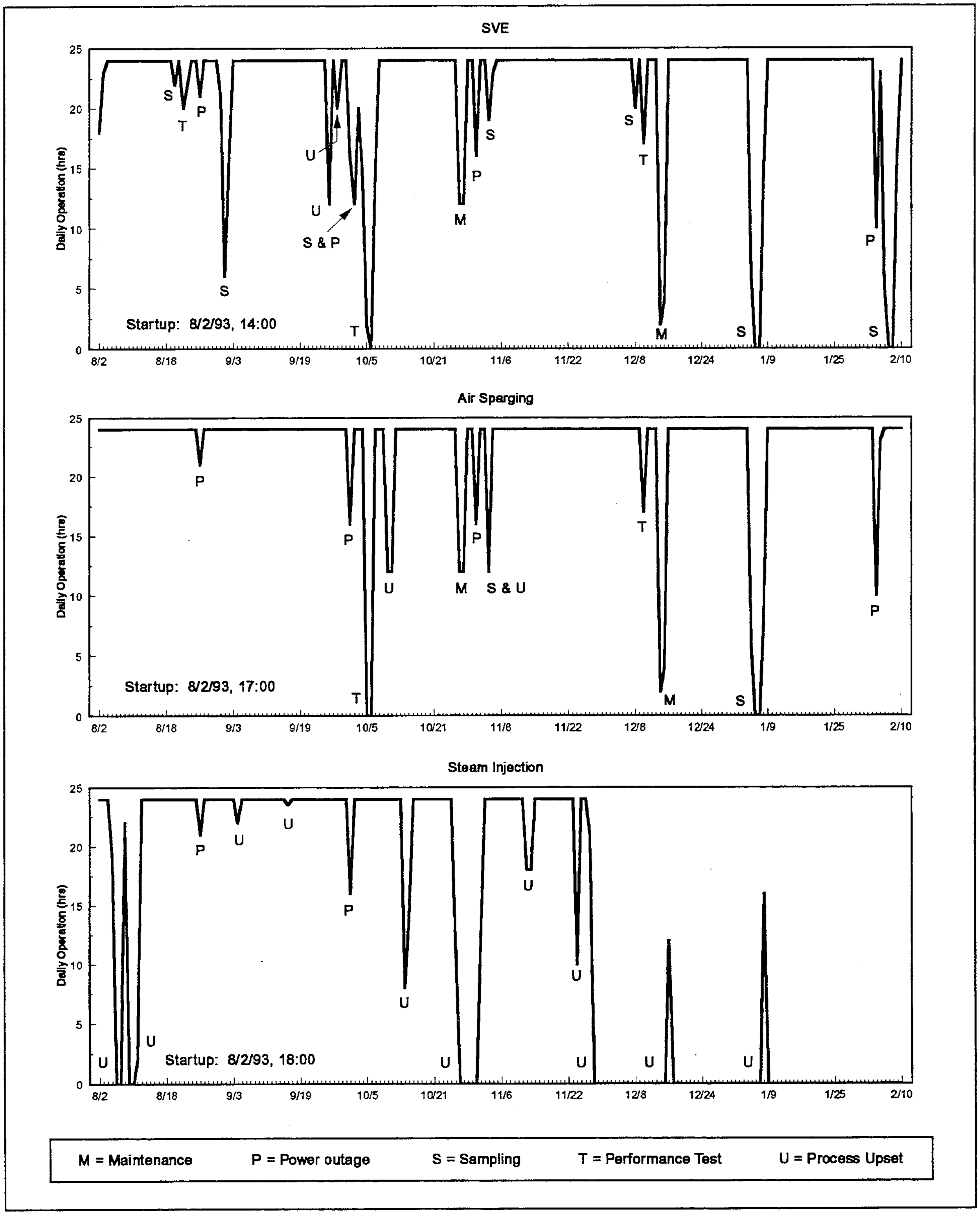


Figure 4-3. Daily Hours of Operation for the Process Components in the West Cell

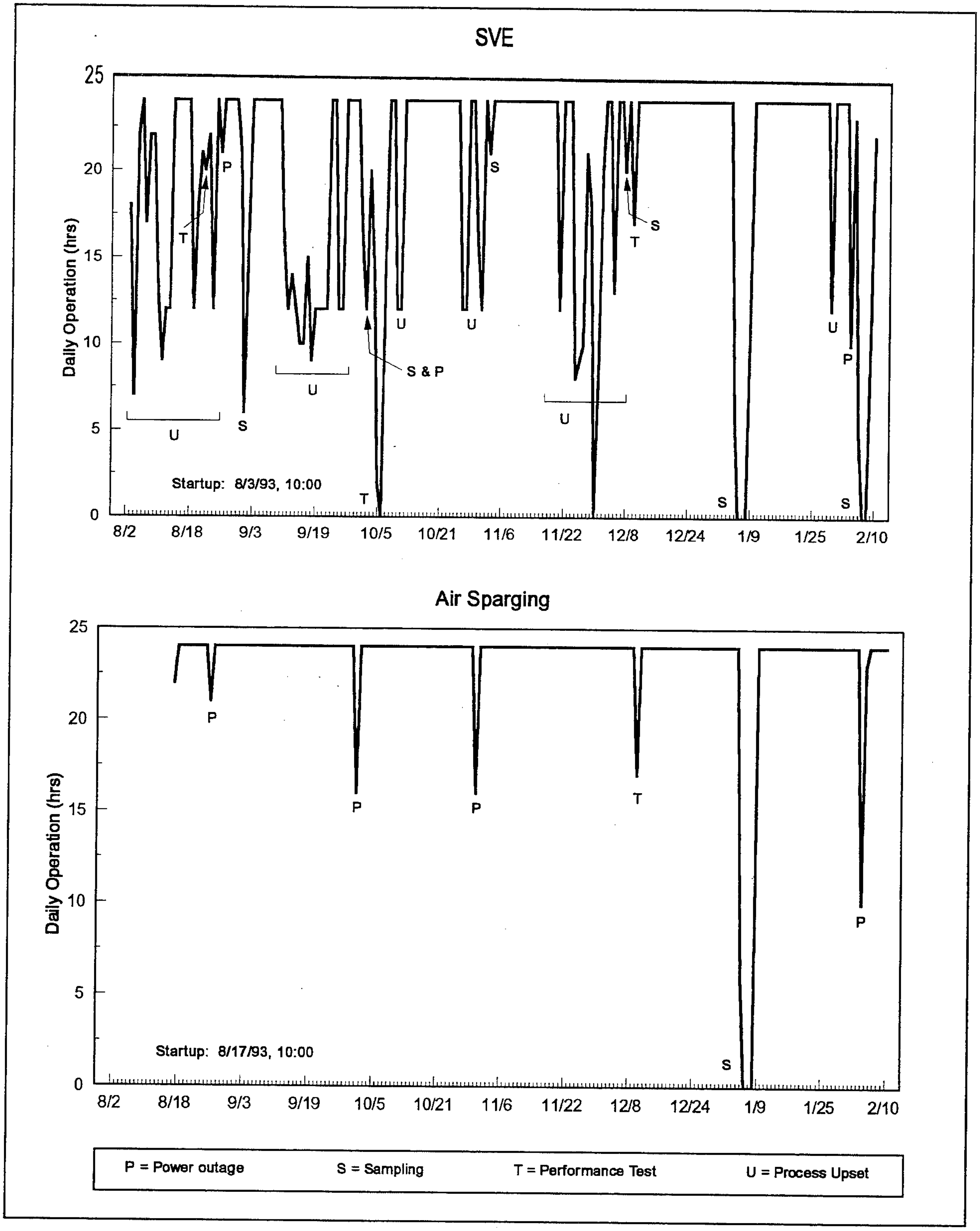


Figure 4-4. Daily Hours of Operation for the Process Components in the East Cell

checks and performance tests, such as air permeability, air sparging (AS) zone of influence, and in situ respiration, are discussed in later subsections.

The monitoring schedule for the Phase II pilot-scale test is presented in Table 4-1, including the number of samples collected for laboratory analysis and the number of field measurements taken during each sampling event. Appendix C.2 contains a description of the sampling and analytical methods used during the pilot-scale test.

Samples were collected during the last week in July before system startup. Samples for soils, soil gas, and groundwater were collected monthly over the six-month test period to monitor the treatment effectiveness of each system. Additionally, field measurements were taken 5 and 15 days after system startup to measure any early change in concentrations of field-determined analytes, such as oxygen, carbon dioxide, VOCs, and dissolved oxygen. The SVE exhaust gas was analyzed to quantify the hydrocarbons removed by the SVE system.

It was clearly apparent during the installation of the monitoring network and treatment wells that the soil cuttings and groundwater from the West Cell had higher VOC concentrations than those from the East Cell. The difference in contaminant distribution patterns was unfortunate in that the two study areas were not comparable.

The analytical results collected during the study are discussed below for the West and East Cells. The results are presented graphically to show trends for the data collected during the test. Appendix C.2 contains the tables that list the results of the soil, groundwater, soil gas, and SVE exhaust gas analyses for the Phase II pilot-scale test.

4.3.1 West Cell Monitoring

Soils

Soil samples were collected from a depth of 9 to 10 ft bgl at approximately 30-day intervals from the beginning of the test through 180 days (the test actually ran 192 days but, for clarity, the results will be discussed by monitoring event; for example, the day 180 event occurred 192 days into the study). The soils were analyzed for TPH, diesel range organics (DRO), gasoline range organics (GRO), and BTEX. Figure 4-5 presents the results for each of these constituents throughout the test. The two sample locations in the southwest part of the West Cell (B-1 and B-6) showed the highest contamination in the study area. The contamination was significantly less in other portions of the study area. These data are presented on a log scale, since the contamination varies by over three orders of magnitude in the West Cell.

Generally, hydrocarbon levels decreased throughout the TS. The TPH and DRO concentrations in B-1 and B-6 decreased by nearly one order of magnitude during the six-month test. The GRO and BTEX also decreased significantly during the study. The initial (Day 0) constituent concentrations at the other soil locations were much lower, ranging from 25 ppm to the detection limit. Samples were not collected at B-5 during the last two sampling events because the soil was frozen and therefore impenetrable by hand augering. This was the only sample location where frozen soil was observed at the sampling depth.

Figure 4-6 shows the microbial plate counts for the soils, including heterotrophic and hydrocarbon-utilizing organisms. The counts for the initial soils were approximately 10^6 to 10^7 heterotrophic organisms, and remained in this range throughout the test period. These numbers indicate that indigenous bacteria are numerous in the POL Tank Farm area, as was previously shown in the Phase I bench-scale test. The numbers of hydrocarbon-utilizing organisms were not as consistent as the numbers of heterotrophic organisms.

During the Day-60 sampling event, steam was observed radiating from the pilot hole at soil location B-6, and mushrooms were growing under the plywood cover. The soil temperatures at depth were measured there and for some of the other soil sample locations. During the later monitoring events, additional temperature measurements were collected at these locations. These data are presented in Figure 4-7. The temperatures in the West Cell remained significantly higher than the ambient temperature throughout the test period. The warmest temperature (45°C) was observed at B-1 on Day 150. For comparison purposes,

Table 4-1
Monitoring Schedule for the Phase II Pilot-Scale Test

Event	Sampling (Days)	Matrix	Field Analyses	Field Samples [b]	Field Duplicates [b,c]	PA Samples [b]	Analytes
G0	0	Gas	18	18	2	1	VOCs*, O_2*, CO_2, TNMHC, BTEX
G1	5	Gas	18	2	2	0	VOCs*, O_2*, CO_2, TNMHC, BTEX
G2	15	Gas	36	4	1	1	VOCs*, O_2*,CO_2, TNMHC, BTEX
G3	30	Gas	36	6	0	0	VOCs*, O_2*,CO_2, TNMHC, BTEX
G4	60	Gas	33	29	4	0	VOCs*, O_2,*CO_2, TNMHC, BTEX
G5	90	Gas	26	4	2	0	VOCs*, O_2,*CO_2, TNMHC, BTEX
G6	120	Gas	38	3	1	1	VOCs*, O_2,*CO_2, TNMHC, BTEX
G7	150	Gas	27	5	0	0	VOCs*, O_2*,CO_2, TNMHC, BTEX
G8	180	Gas	31	28	3	1	VOCs*, O_2*,CO_2, TNMHC, BTEX
S0	0	Soil	12	24	3	0	TPH, DRO, GRO, BTEX, TRPH*, Moisture, EC, NO_3, NH_4, PO_4, TOC, Microbial counts
S1	30	Soil	0	12	0	0	TPH
S2	60	Soil	0	12	1	0	TPH, DRO, GRO, BTEX, Moisture, Microbial counts
S3	90	Soil	0	12	0	0	TPH
S4	120	Soil	0	12	0	0	TPH, DRO, GRO, BTEX, Moisture, Microbial counts
S5	150	Soil	0	12	1	0	TPH
S6	180	Soil	0	12	1	0	TPH, DRO, GRO, BTEX, Moisture, EC, NO_3, NH_4, PO_4, TKN, pH, TOC, Microbial counts
W0	0	GW	8	8	1	0	DO*, TPH, DRO, GRO, BTEX, TRPH*, Microbial counts, NO_3, NH_4, PO_3
W1	30	GW	8	0	0	0	DO*, TRPH*
W2	60	GW	8	0	0	0	DO*, TRPH*
W3	90	GW	8	0	0	0	DO*, TRPH*
W4	120	GW	8	0	0	0	DO*, TRPH*, Microbial counts
W5	150	GW	8	0	0	0	DO*, TRPH
W6	180	GW	8	0	1	0	DO*, TPH, DRO, GRO, BTEX, Microbial counts, NO_3, NH_4, PO_4

Notes: *Field measurement. [a]G = Gas sampling event, S = soil sampling event, W = groundwater sampling event. [b]Sample collected for off-site laboratory analysis. [c]Field duplicates are replicate samples for quality assurance analysis. BTEX = Benzene, toluene, ethylbenzene, xylenes. DRO = Diesel range organics. EC = Electrical conductivity. GRO = Gasoline range organics. GW = Groundwater. PA = Performance audit (calibration gases used for quality assurance analysis). TKN = Total Kjeldahl nitrogen. TNMHC = Total non-methane hydrocarbons. TPH = Total petroleum hydrocarbons. TOC = Total organic carbon. TRPH = Total recoverable petroleum hydrocarbons. VOCs = Volatile organic compounds.

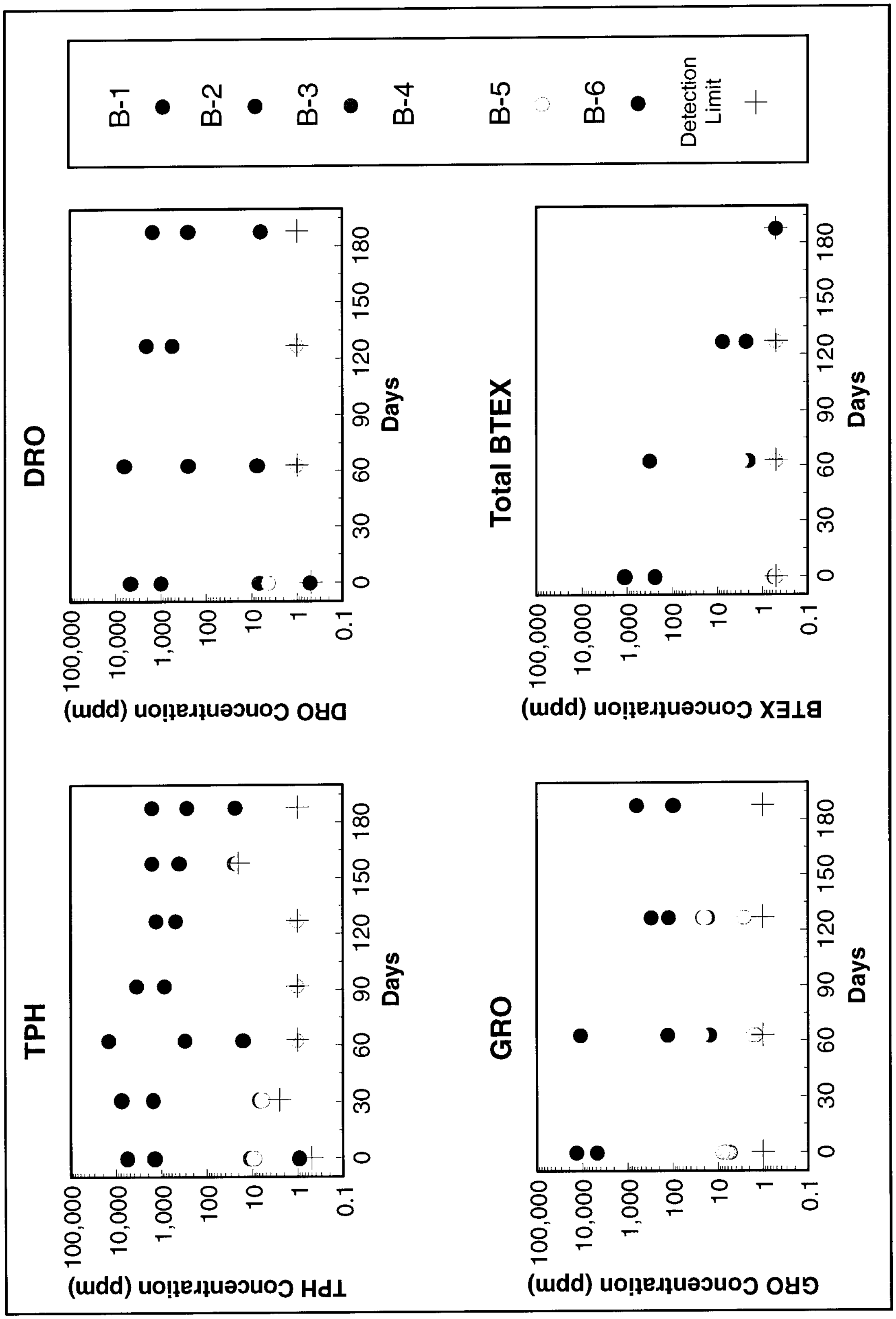


Figure 4-5. Constituent Concentrations in Soils from the West Cell

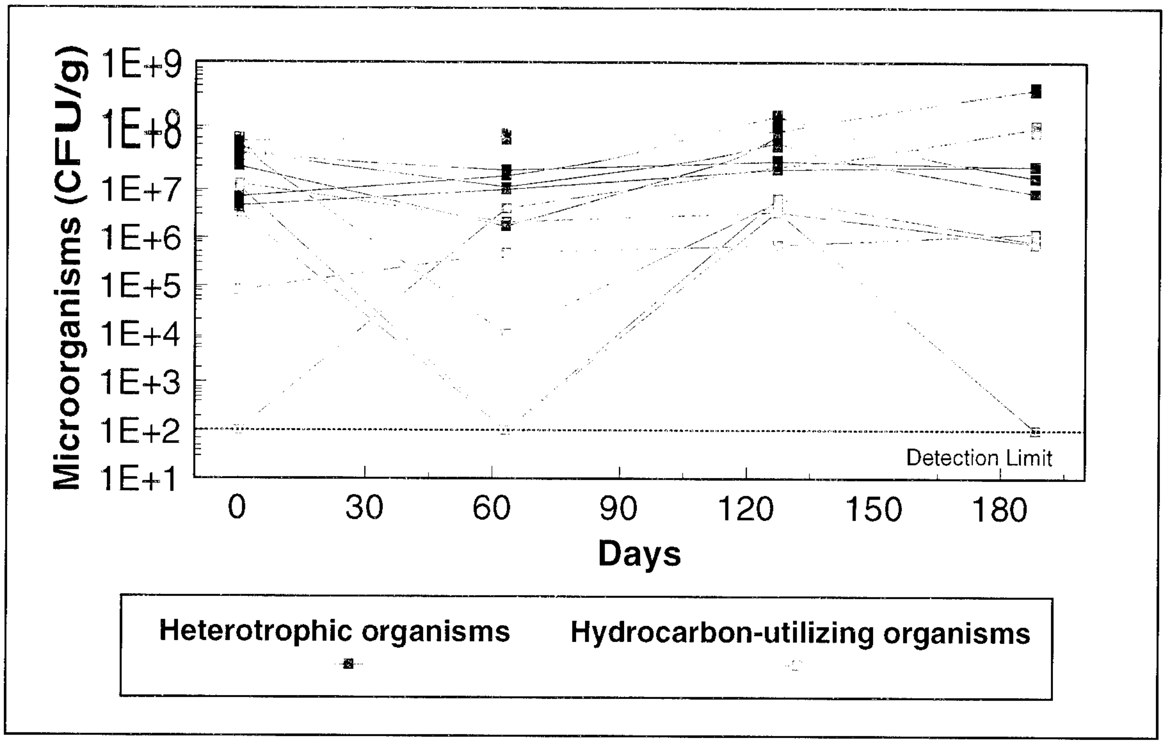


Figure 4-6. Microbial Plate Counts for Soils Collected in the West Cell. Lines connecting points indicate temporal trends for each sample location.

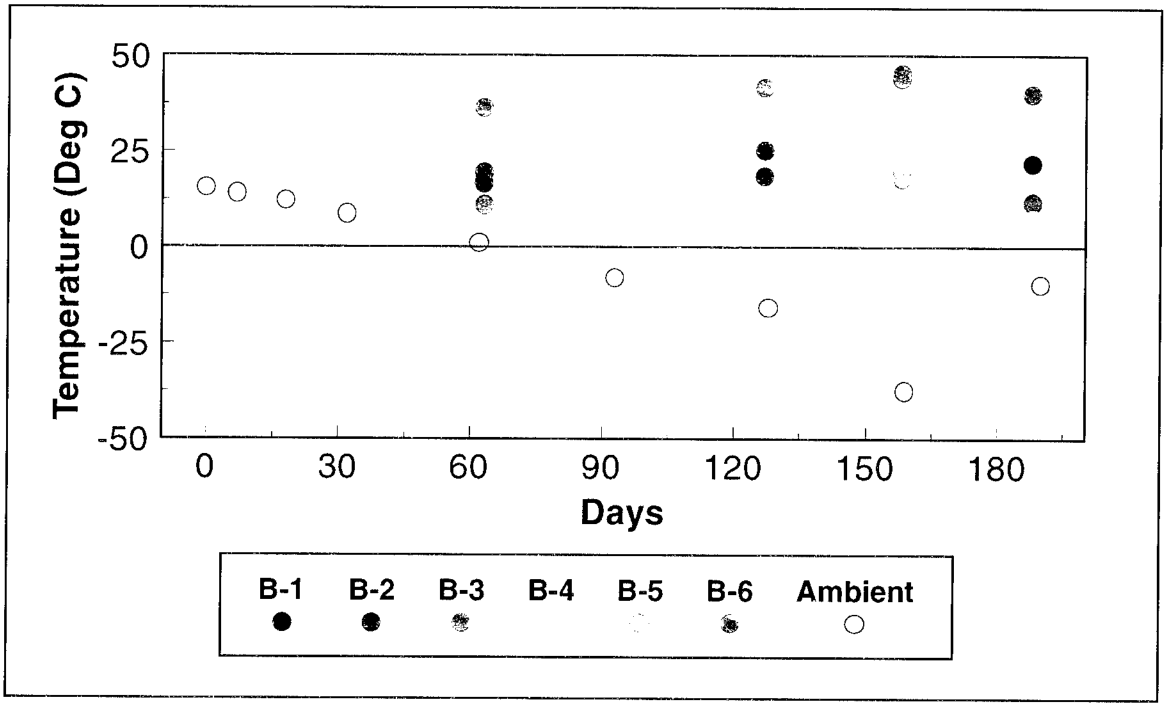


Figure 4-7. Soil Temperatures Measured in the West Cell

the average soil gas temperature in the East Cell at that time was 7° C. After considering possible causes for the temperature rise, it was concluded that the heat in the West Cell was not attributable to steam injection but was generated through biological activity. Section 5.6 discusses this hypothesis in greater detail.

Groundwater

Groundwater samples were collected for laboratory analysis around Days 0 and 180 and for field analyses around Days 0, 30, 60, 90, 120, and 150. The initial characterization of the groundwater showed nondetectable concentrations of nutrients (nitrogen as ammonia and nitrate and phosphorous as phosphate), low levels of microorganisms (10^2 to 10^3 CFU/g), and significant levels of hydrocarbon constituents.

Water levels and free-product thicknesses were measured during each sampling event. Figure 4-8 shows the groundwater fluctuation at the POL Tank Farm in relation to the Phase II test. Figure 4-9 presents the observed free-product thicknesses in the monitor wells. Before startup, no floating free-product layer was observed on the water table. As the water table began declining in September, a free-product layer was observed in all of the monitor wells in the West Cell. The apparent thicknesses in three wells remained at 1 to 2 ft throughout the remainder of the study.

Table 4-2 presents the results of the laboratory analysis of groundwater from the West Cell. Owing to the scarcity of data points (only initial and final), a thorough analysis of the treatment effectiveness is not possible. The evaluation of constituent concentrations in the groundwater is further complicated by the fluctuating water table and the presence of free product. Attempts were made to purge the free product from the monitor well, but the hydrocarbon recovery in the wells was generally rapid. The purging also tended to create an emulsion of free product and groundwater. The GRO and BTEX concentrations in the groundwater increased during the study probably as a result of the free-product layer contributing dissolved-phase contaminants to the groundwater. Free product was not seen in the monitor wells when the initial samples were collected.

Table 4-2
Constituent Concentrations in the Groundwater from the West Cell

Monitor Well	Analyte	Concentration (ppm)	
		Initial[a]	Final[b]
W-1	TPH	302	64
	DRO	195	23
	GRO	521	511
	BTEX	80	129
W-2	TPH	21	41
	DRO	11	4.6
	GRO	98	353
	BTEX	50	117
W-3	TPH	98	10
	DRO	50	0.4
	GRO	4.4	152
	BTEX	6.2	108
W-4	TPH	97	200
	DRO	57	311
	GRO	37	236
	BTEX	25	400

Notes: [a]Samples collected at Day 0. [b]Samples collected at Day 189.

Groundwater analyses for total recoverable petroleum hydrocarbons (TRPH) were also performed in the field with an infrared detector. Figure 4-10 presents the field analytical results. The data collected around Day 120 probably contained some free product, as determined by the concentration measured and visual observations. From these data, the TRPH concentrations in the West Cell groundwater appeared to remain constant or increase over time. Most likely, the dissolved-phase concentrations were high because free product was contributing contaminants to the groundwater.

Soil Gas

Soil gas samples were collected in stainless steel vacuum canisters for laboratory analyses at various intervals throughout the study. All vapor probes were sampled on Days 0, 60, and 180. Since the deep vapor probes could not be installed until the water table dropped below the depth of installation, samples for the deep probes were not collected until Day 30. Field measurements were taken at the installed probes at 30-day intervals and also on Days 5 and 15.

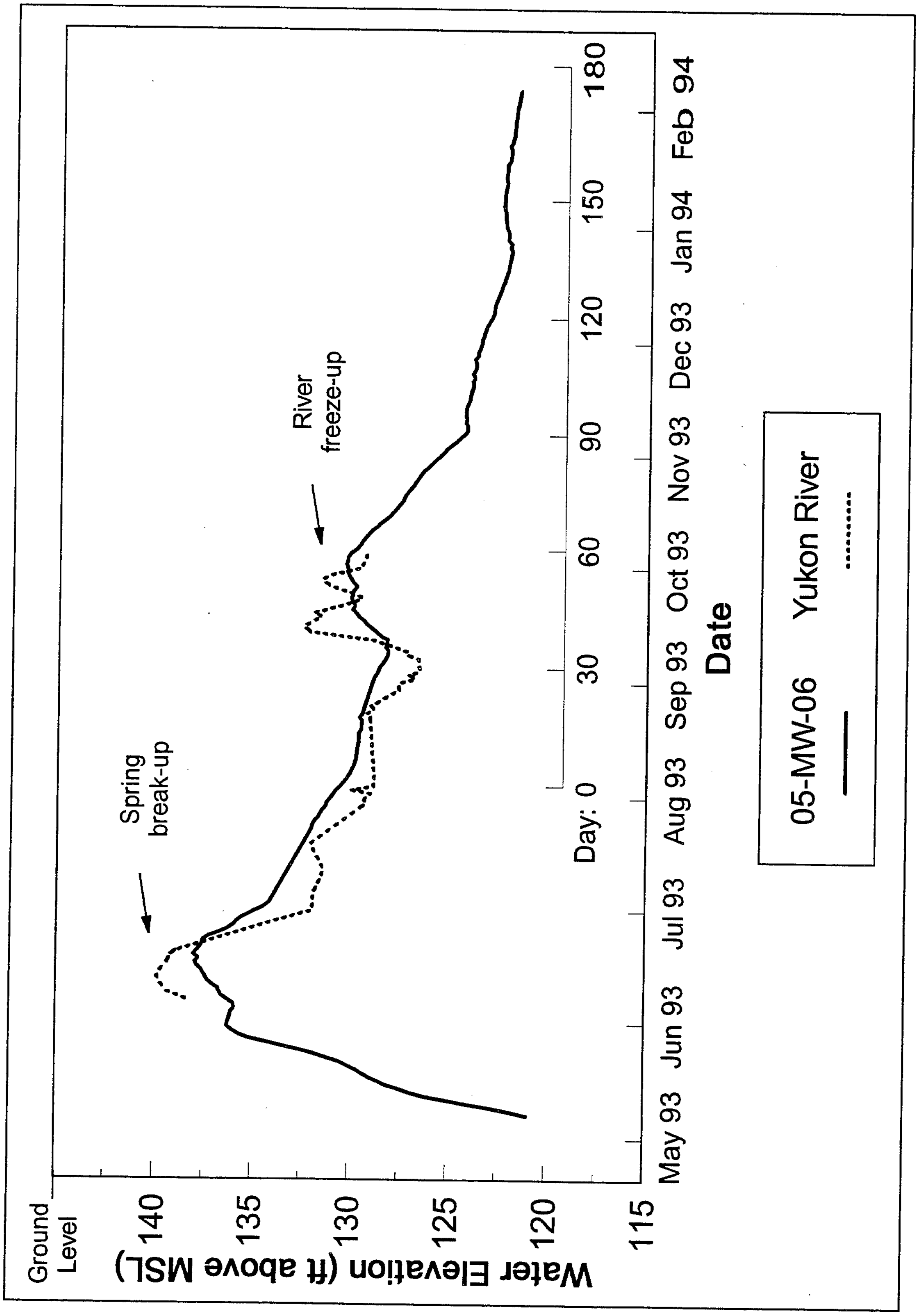


Figure 4-8. **Water Level Fluctuations in the POL Tank Farm and for the Yukon River During the Test Period. The Sampling Events are Marked for Reference.**

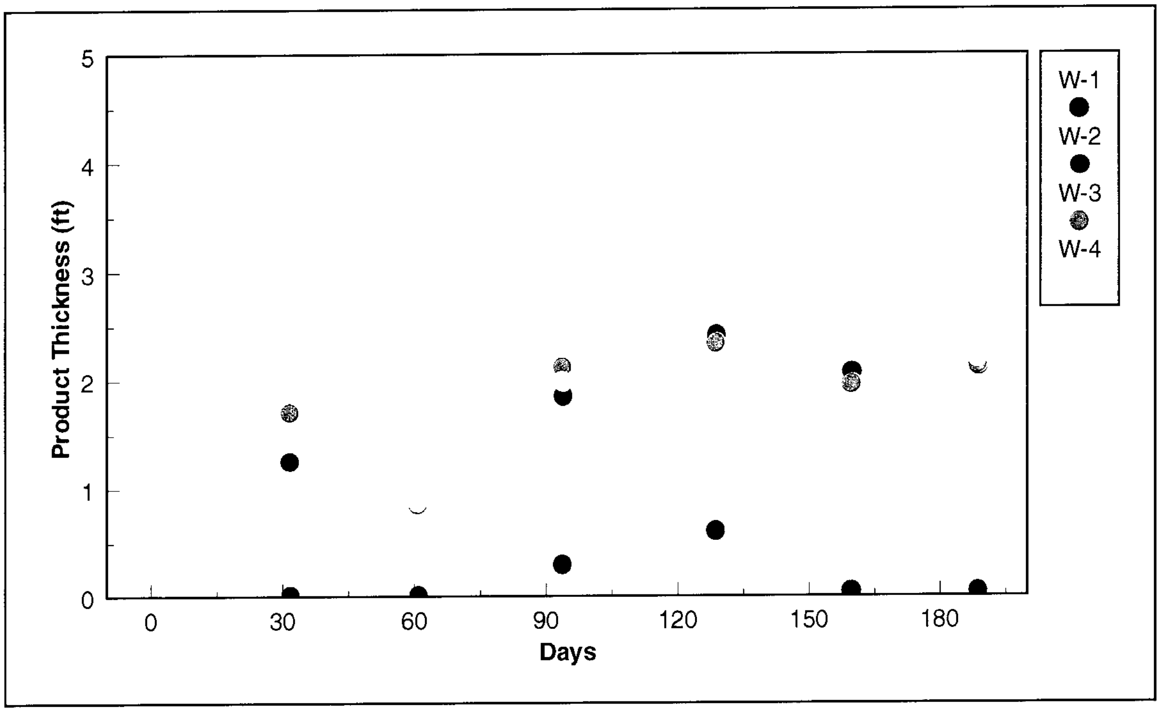


Figure 4-9. Observed Free Product Thicknesses in the Monitor Wells at the West Cell

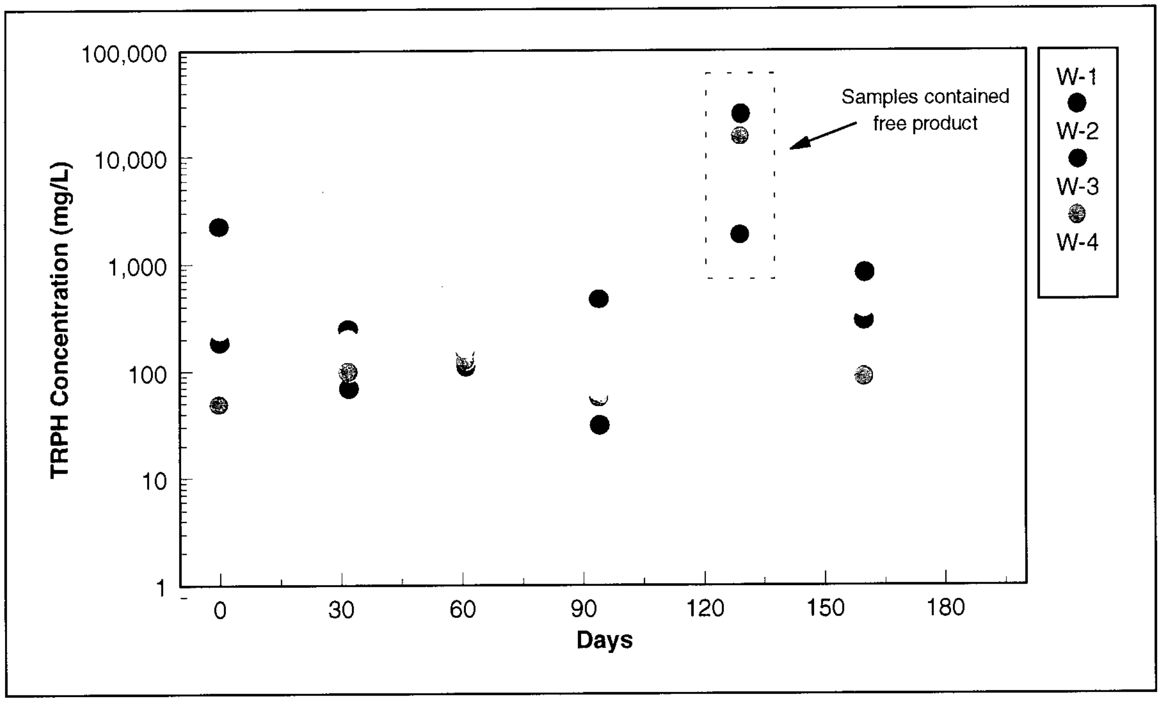


Figure 4-10. Field Analytical Results for the Groundwater from the West Cell

The laboratory analyses for the soil gas included TNMHC and BTEX. Figure 4-11 shows these data, which are grouped as V-1 through V-4 and V-5 through V-10 and by depth. V-1 through V-4 are located in the western half of the West Cell. Generally, the VOC concentrations decreased over time. The data confirmed other observations that the major zone of contamination was the western portion of the study area.

Figure 4-12 presents the oxygen and carbon dioxide concentrations as a function of time. The oxygen and carbon dioxide concentrations were highly variable across the cell. The initial soil gas measurements were taken prior to starting the SVE system—these data indicate O_2 and CO_2 levels in the static (no gas flow) condition. Soon after system startup, most of the vapor probe locations showed soil gas concentrations similar to ambient air (21% O_2 and 0.03% CO_2). This trend is attributed to ambient air being pulled through the subsurface by the vacuum induced by the SVE system. For the deep vapor probes, the time required to reach steady-state values was somewhat longer than it was for the shallow probes.

During the monitoring period, some of the soil gas showed elevated carbon dioxide and depressed oxygen concentrations. However, sufficient O_2 was present to support aerobic microbial metabolism at all locations. For the vapor probes in the western portion of the study area (V-1 through V-4), the established steady-state concentrations were 13% to 15% oxygen and 5% to 7% carbon dioxide. These vapor probes are located in the area containing the highest hydrocarbon concentrations and also experienced elevated soil temperatures (see Figures 4-11 and 4-13). Since a decrease in oxygen and an increase in carbon dioxide is typical of an aerobic biological process, the combination of high soil temperatures, high carbon dioxide levels, and greatest hydrocarbon concentrations substantiates the hypothesis that biodegradation rates were enhanced in the western portion of the West Cell.

4.3.2 East Cell Monitoring

Soils

Soils samples in the East Cell were collected from 9 to 10 ft bgl on the same 30-day schedule as in the West Cell. Figure 4-14 presents the results of the soil analyses. Sample location B-7 showed the greatest contamination in the East Cell, which was greatest at Day 60. The contaminant concentrations then decreased steadily to below the method detection limit by Day 180. At the end of the test period, constituent concentrations at all locations were below the detection limit.

During the installation of the IAS wells in the East Cell, little contamination was present on the east side of the study area. Therefore, the soil sampling locations were concentrated on the west side, where the contamination was observed to be highest, on the basis of field VOC measurements.

Figure 4-15 presents the microbial plate count results for the East Cell. As in the West Cell, the heterotrophic microbial population was very healthy (10^6 to 10^8). The soil temperatures measured in the East Cell are shown in Figure 4-16. The soil temperatures remained near 6°C throughout the test period. The greatest soil temperature in the East Cell (18°C) was observed at B-8 on Day 150.

Groundwater

Groundwater samples were collected for laboratory analysis on Days 0 and 180 and for field analyses around Days 0, 30, 60, 90, 120, and 150. The initial characterization of the groundwater showed non-detectable concentrations of nutrients and low levels of microorganisms (10^2 to 10^4 CFU/g); however, the heterotrophic organisms were enumerated initially at 10^6 for W-7.

Figure 4-17 presents the observed free-product thicknesses in the monitor wells at the East Cell during the test period. Before startup, free product was found in W-8, which was located south of the study area. The free-product thickness decreased over the study period, disappearing entirely by Day 150. The other wells showed no accumulation of free product during the test.

Table 4-3 presents the laboratory analytical results for the groundwater from the East Cell. For monitor well W-8, the GRO and BTEX concentrations decreased during the test. The free-product thickness in this well also decreased during this period, which could explain the decrease in GRO and BTEX levels. Little

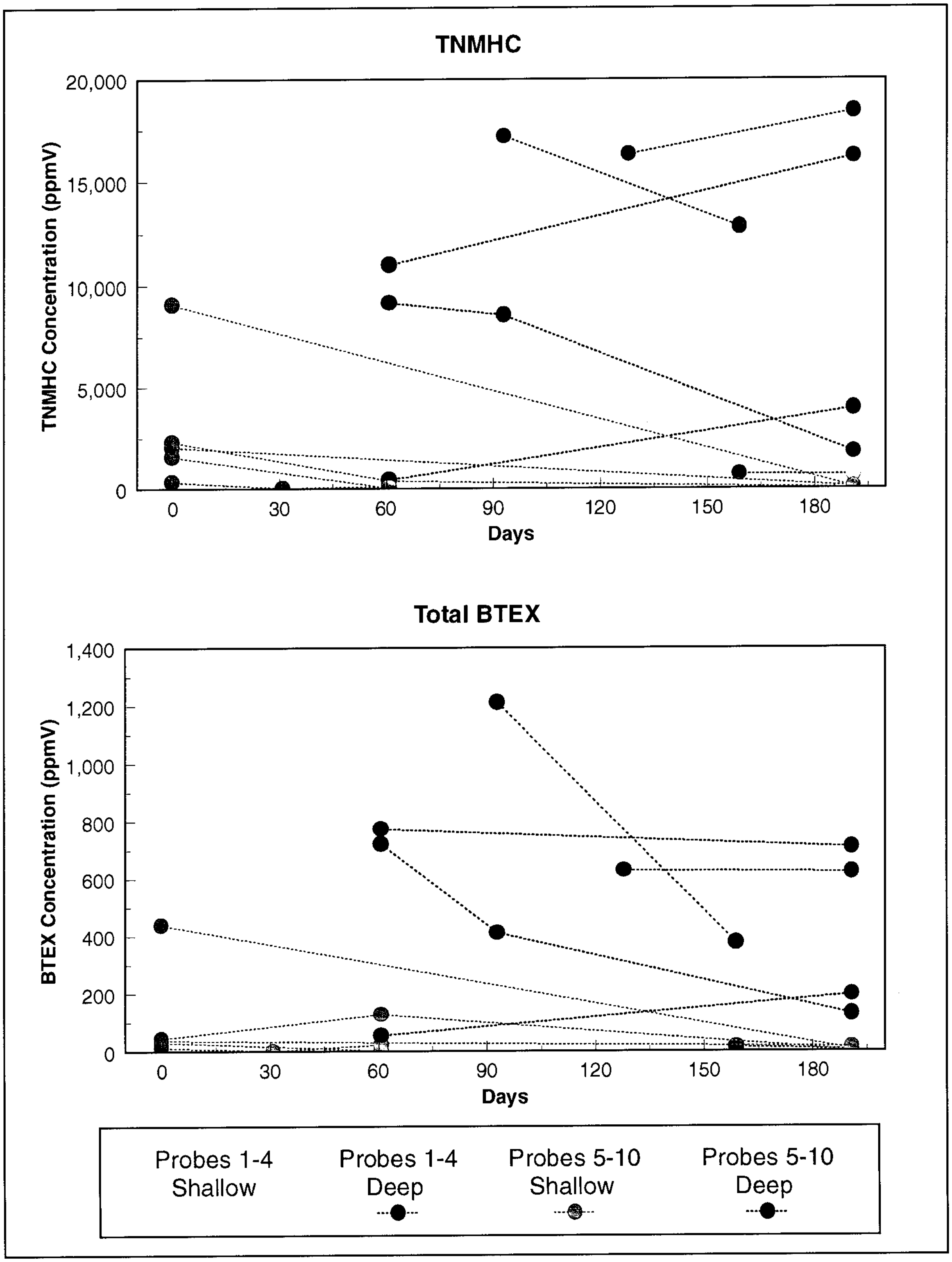


Figure 4-11. Total Non-Methane Hydrocarbons and BTEX Concentrations in the Soil Gas at the West Cell. Vapor Probes are Grouped by Soil Contamination Levels and Biological Activity.

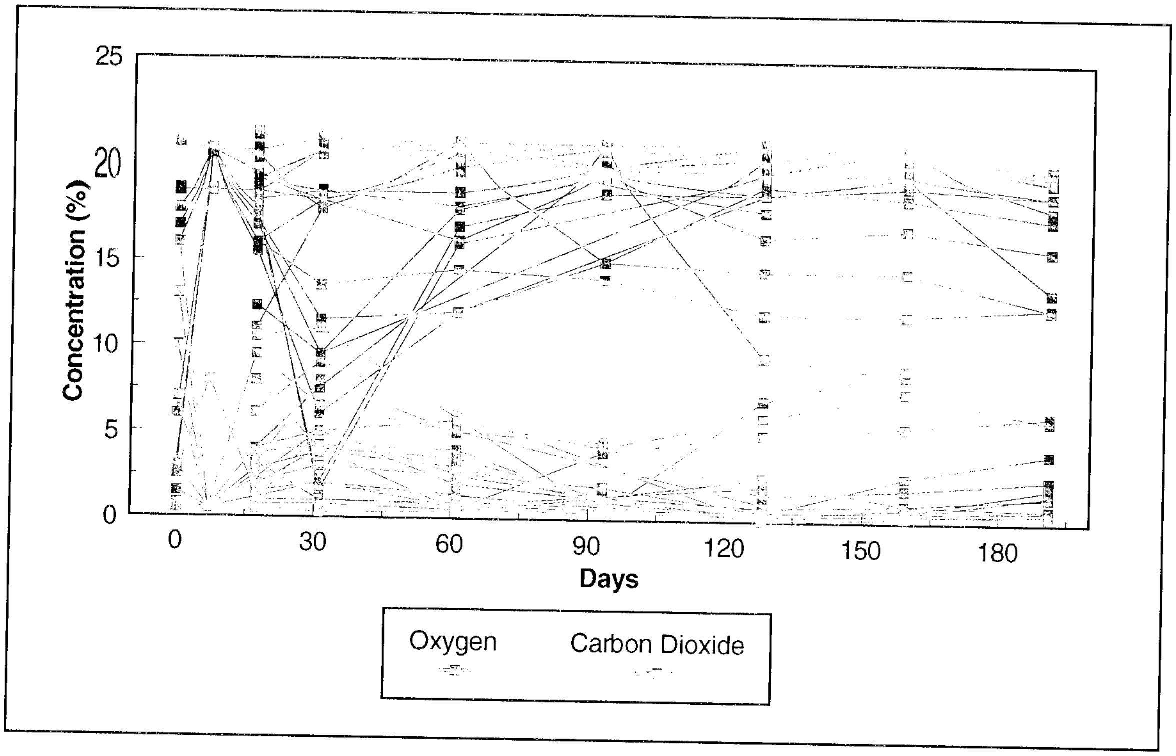


Figure 4-12. Oxygen and Carbon Dioxide Concentrations Measured in the Soil Gas at the West Cell. Connecting lines indicate temporal changes for each vapor probe.

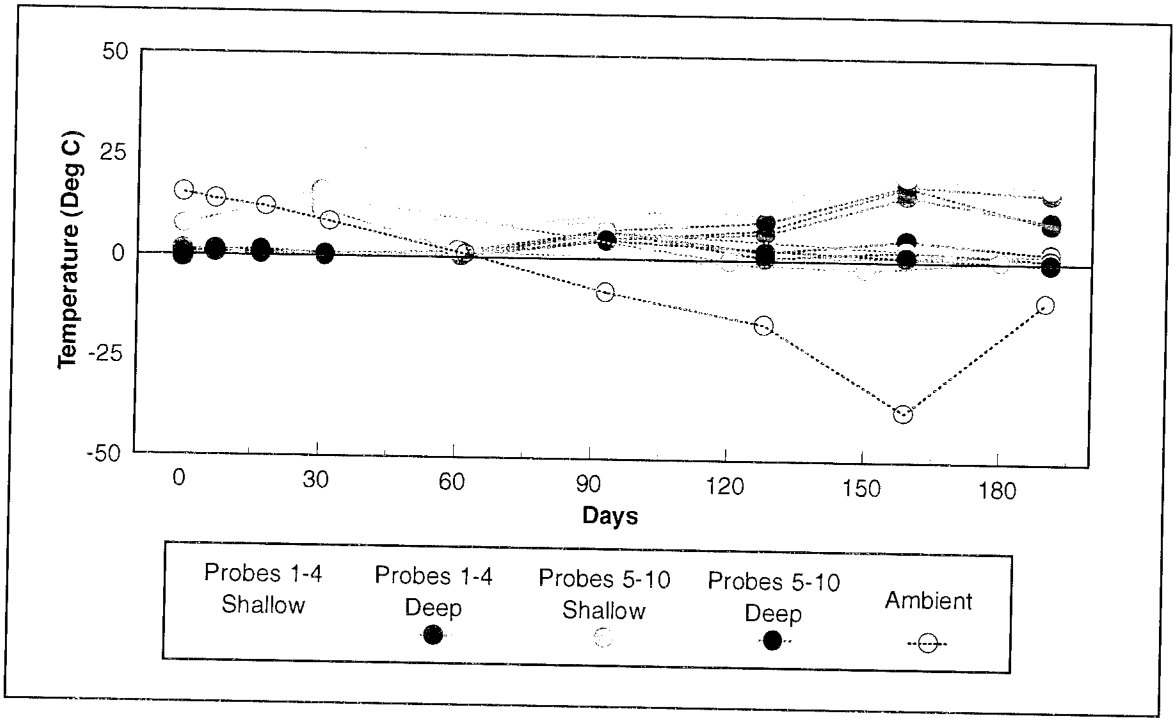


Figure 4-13. Soil Gas Temperatures Measured at the West Cell

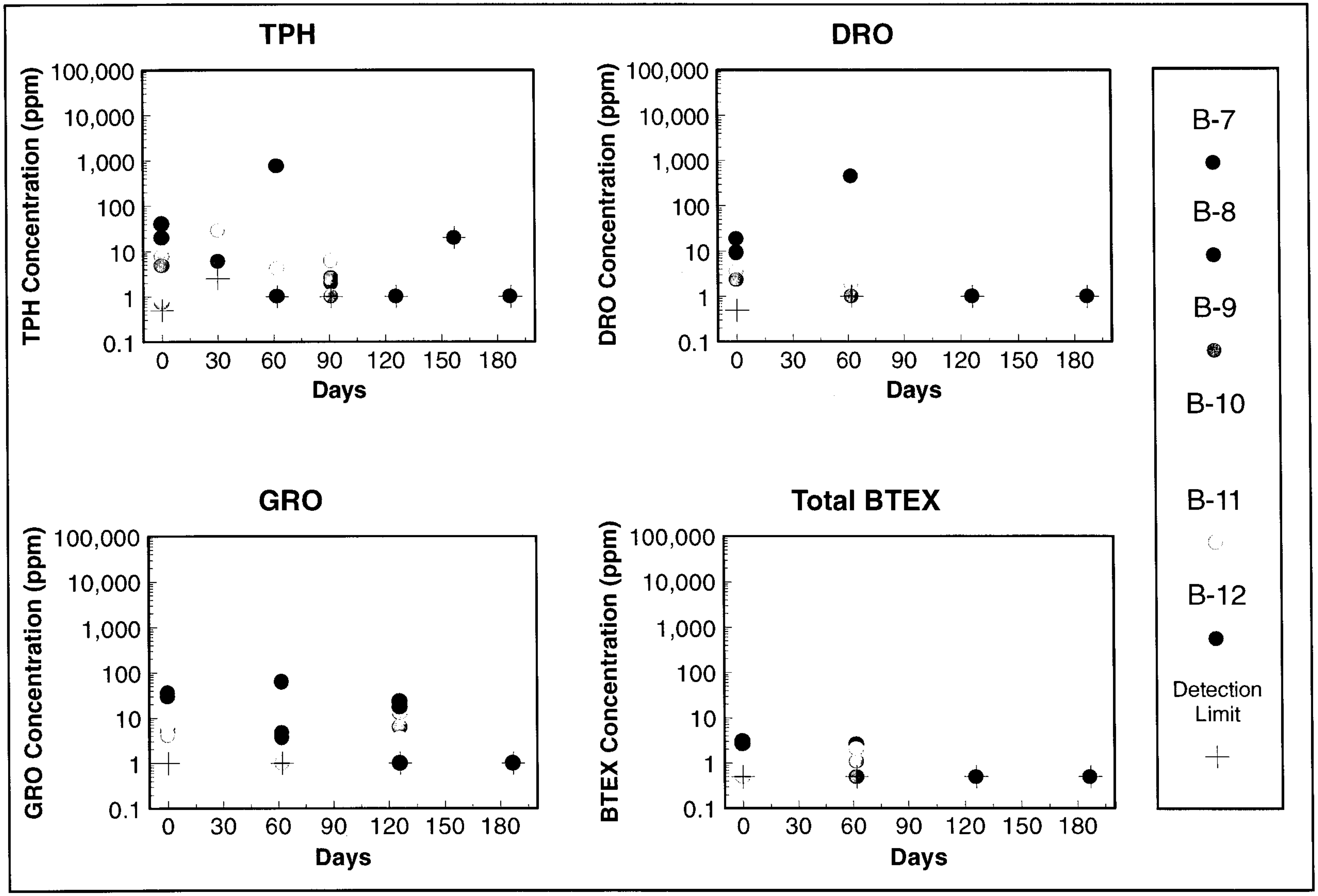


Figure 4-14. Constituent Concentrations in Soils from the East Cell

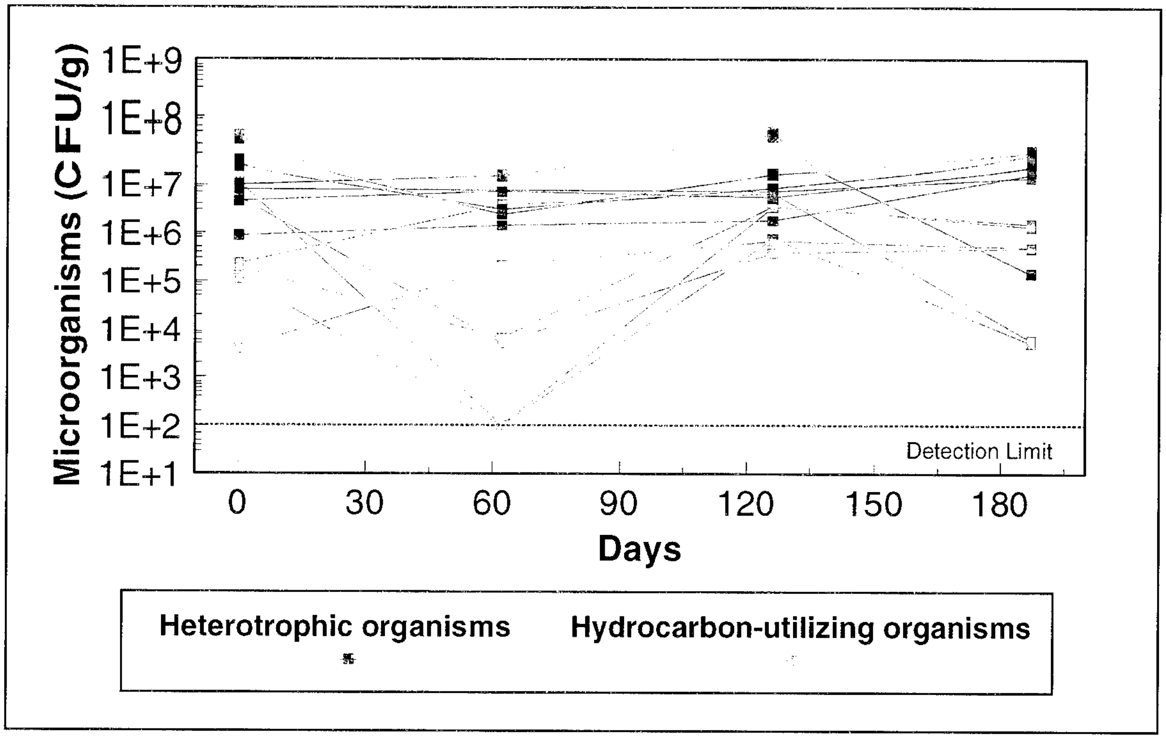


Figure 4-15. Microbial Plate Counts for Soils Collected in the East Cell. Lines connecting points indicate temporal trends for each sampling location.

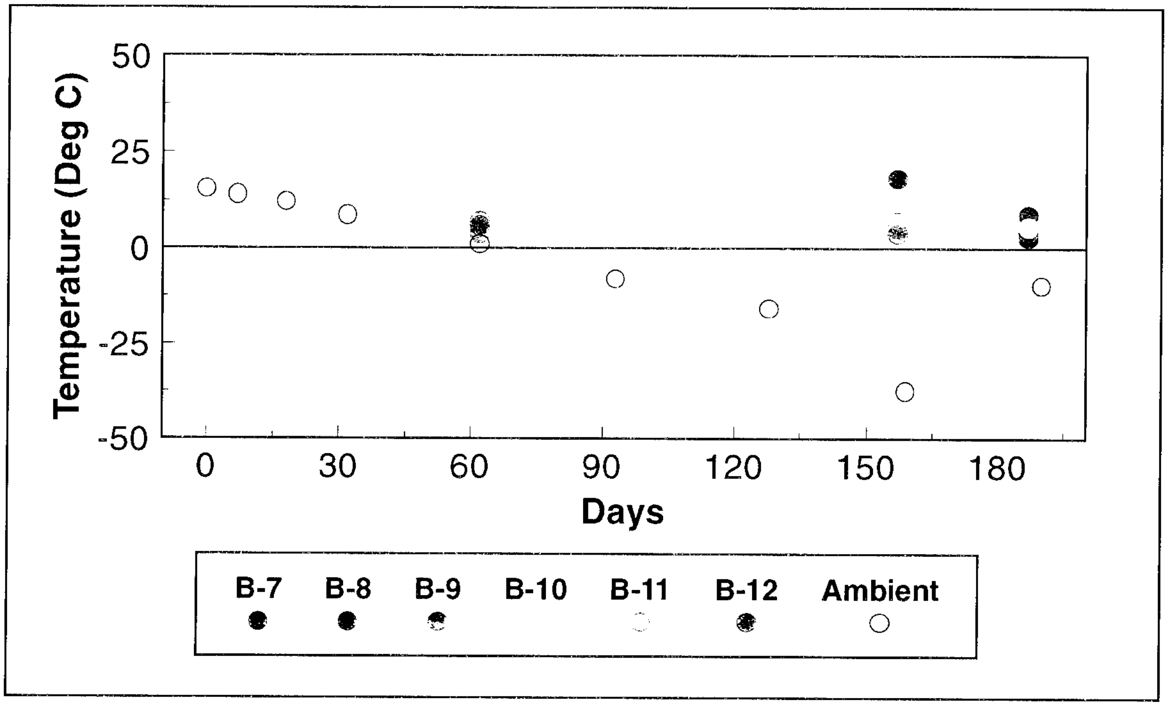


Figure 4-16. Soil Temperatures Measured in the East Cell

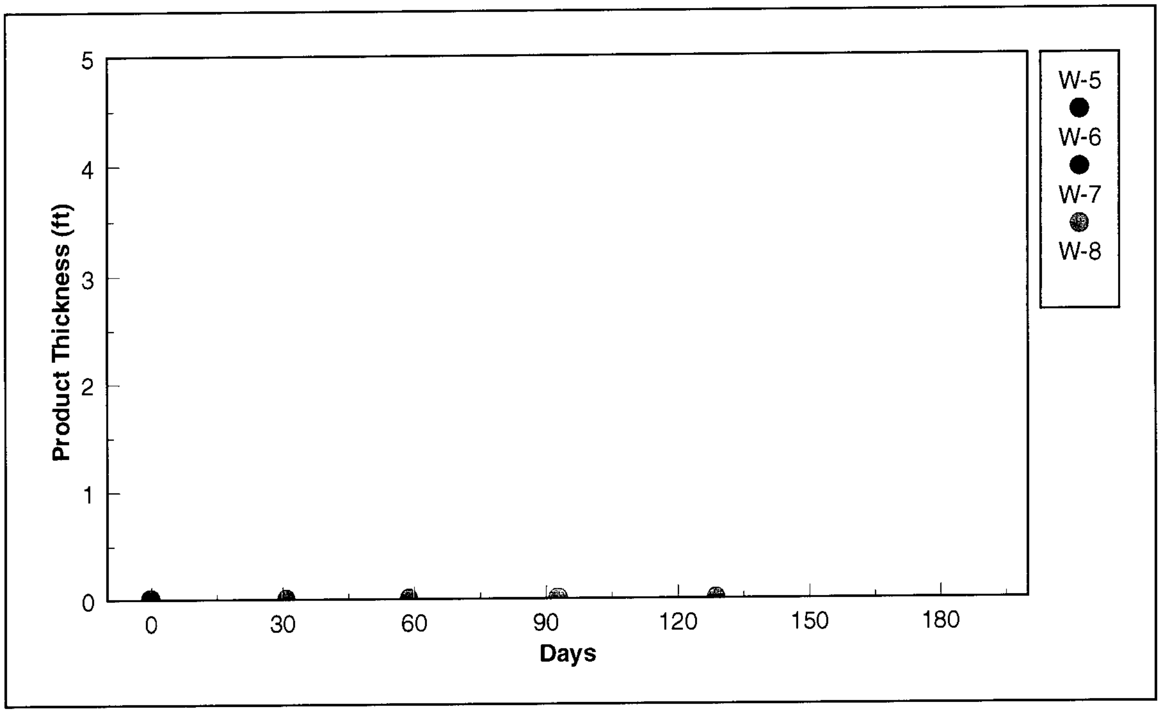


Figure 4-17. Observed Free Product Thicknesses in the Monitor Wells at the East Cell

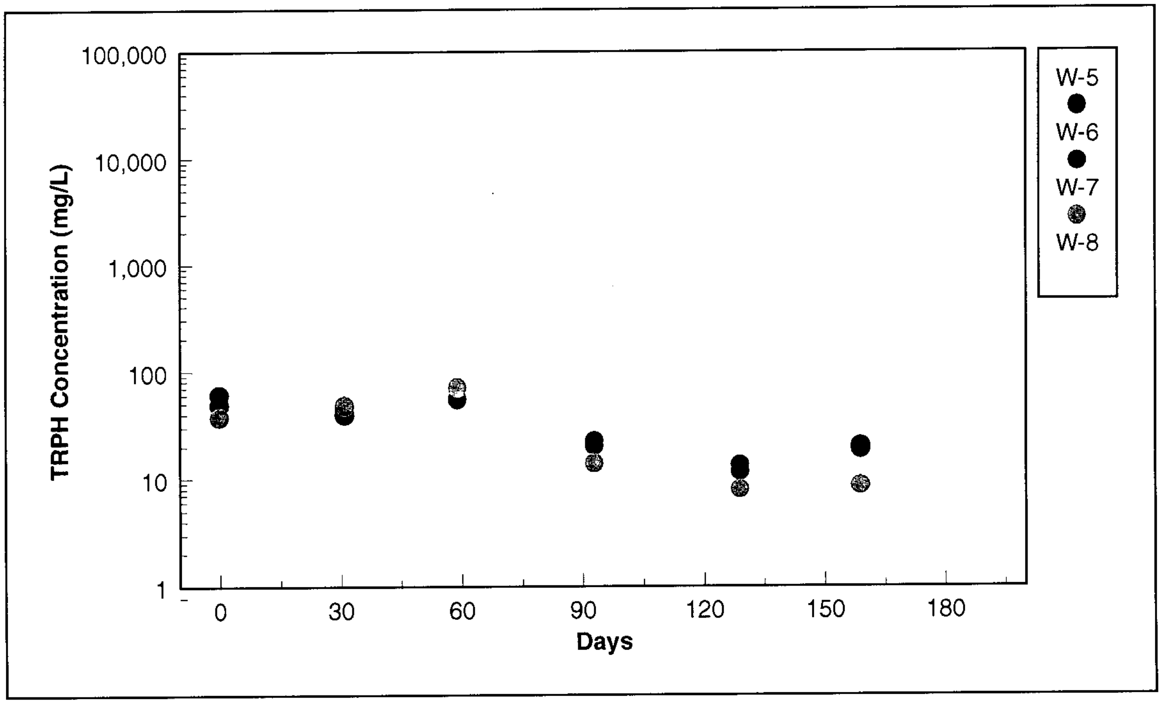


Figure 4-18. Field Analytical Results for the Groundwater from the East Cell

or no change in DRO and TPH concentrations in this well suggests that the free product primarily contains the lighter constituents (more volatile) found in gasoline.

Table 4-3
Constituent Concentrations in the Groundwater from the East Cell

Monitor Well	Analyte	Concentration (ppm)	
		Initial[a]	Final[b]
W-5	TPH	7.3	37
	DRO	0.3	1.6
	GRO	75	137
	BTEX	51	98
W-6	TPH	0.1	30
	DRO	0.1	2.1
	GRO	92	106
	BTEX	41	65
W-7	TPH	7.1	24
	DRO	1	0.8
	GRO	146	88
	BTEX	67	50
W-8	TPH	19	33
	DRO	12	2.8
	GRO	2115	159
	BTEX	293	98

Notes: [a]Samples collected at Day 0. [b]Samples collected at Day 188.

Groundwater analyses performed in the field with the infrared detector are presented in Figure 4-18. From these data, it appears that the TRPH concentrations decreased over time. Again, the accumulation of free product on the water table at W-8 probably contributed to the dissolved-phase concentrations in the initial samples of the groundwater.

Soil Gas

Samples were collected for soil gas analyses at various intervals throughout the study. Figure 4-19 presents these analytical results. Generally, the concentrations decreased over time. Again, the greatest contamination was seen in the western portion of the study area. Individual vapor probe results are contained in Appendix C.2.

Figure 4-20 presents the oxygen and carbon dioxide concentrations as a function of time. The soil gas showed concentrations that leveled out to near ambient air conditions (21% O_2 and 0.03% CO_2) for all sampling locations. This trend was expected, since ambient air was pulled through the subsurface by the SVE system.

Figure 4-21 presents the soil gas temperature data for the test. Generally, the temperatures decreased as the ambient temperature declined and leveled off above 0° C.

4.4 Process Performance Measurements

Various process variables were monitored daily to ensure the proper operation of the equipment and to estimate the SVE hydrocarbon removal rates. Table 4-4 lists the system performance parameters that were monitored on a daily basis throughout the test period. Other performance measurements, such as air permeability tests, in situ respiration tests, and air sparging tracer tests, were conducted on one or more occasions. The following subsections describe the daily operational and intermittent performance monitoring results.

Table 4-4
Summary of Process Variables Monitored Daily During the Phase II Test

SVE System	IAS System
Running Time	Running Time
System Vacuum	Outlet Temperature
Inlet Diff. Pressure	Outlet Pressure
Inlet Temperature	Outlet Flow Rate
Exhaust Diff. Pressure	Header Pressure
Exhaust Temperature	**Steam Injection System**
Exhaust Back Pressure	Running Time
Exhaust HC Concentration	Flow Totalizer
Volume in Knockout Tank	Steam Flow Rate
General	Outlet Pressure
Barometric Pressure	Header Pressure
Ambient Temperature	Feedwater Pressure
Relative Humidity	Water Tank Level
Enclosure Temperature	

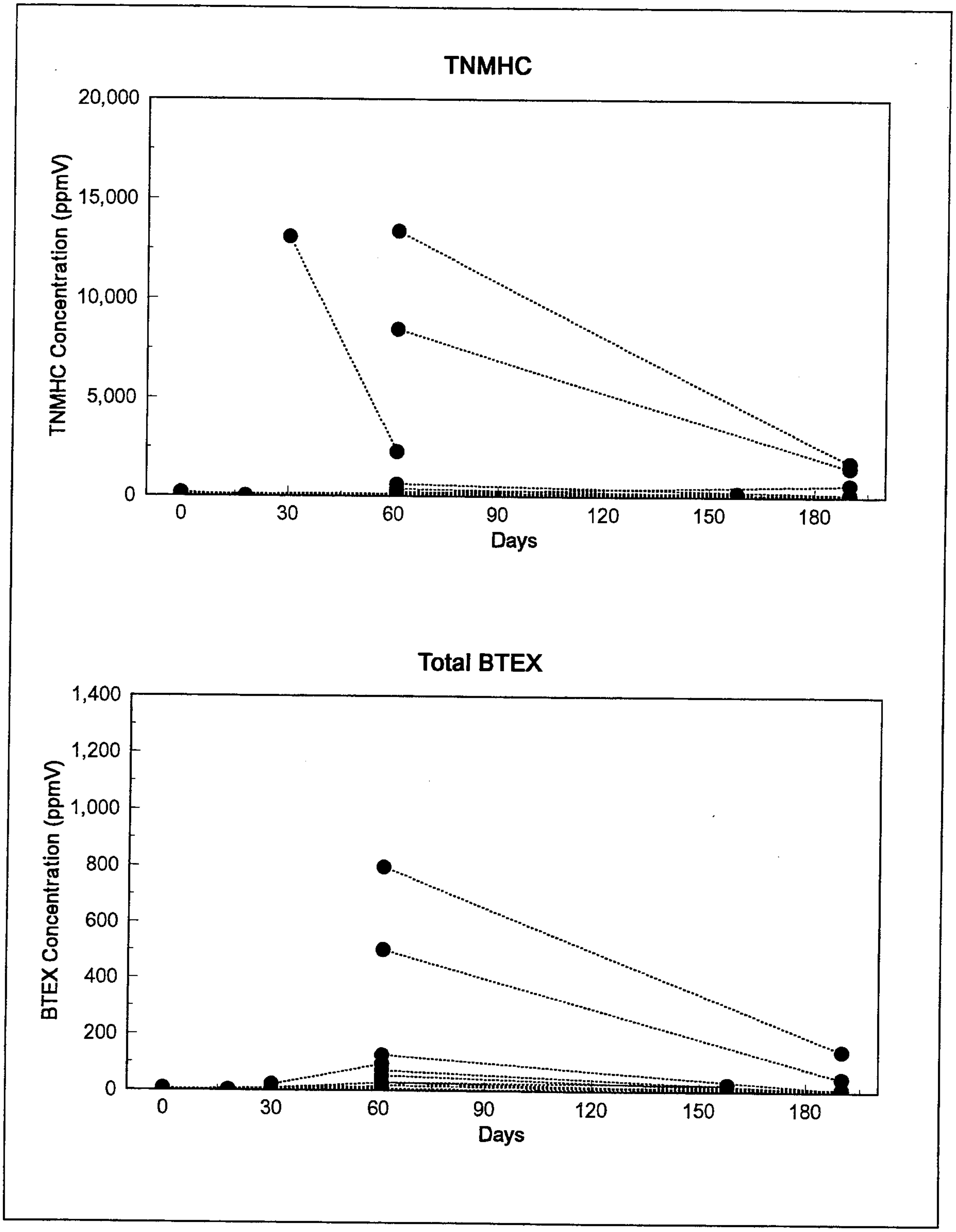


Figure 4-19. Total Non-Methane Hydrocarbons and BTEX Concentrations in the Soil Gas at the East Cell

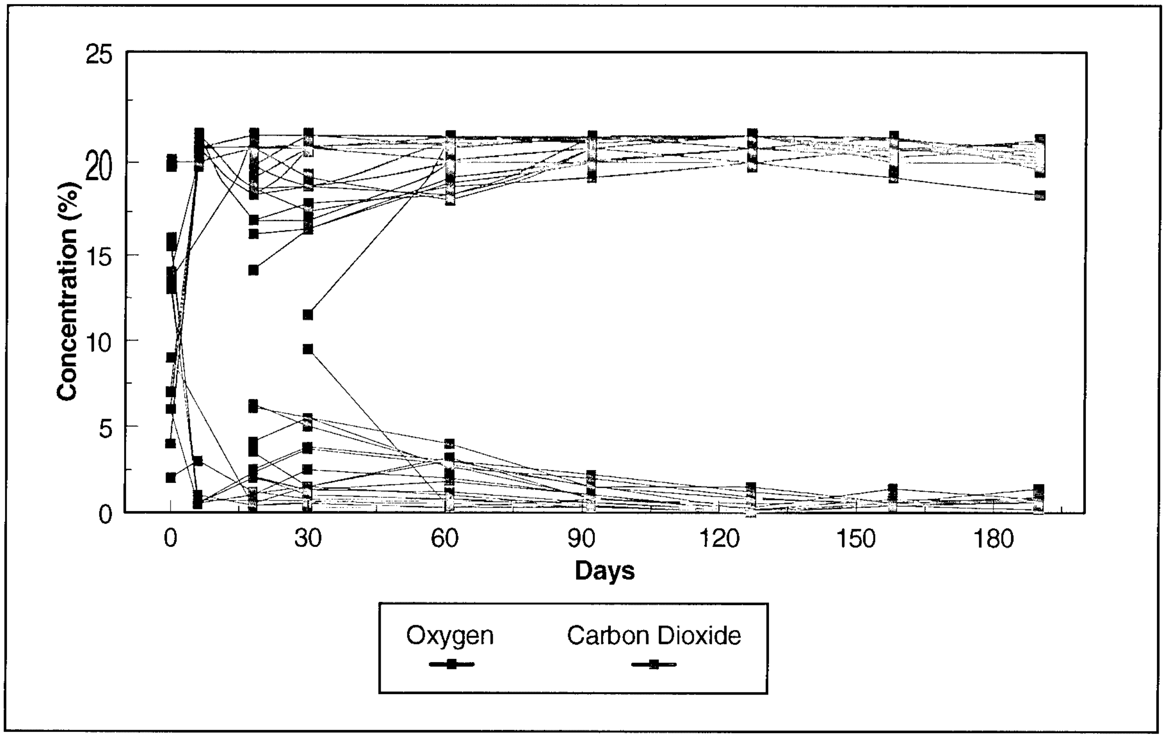


Figure 4-20. Oxygen and Carbon Dioxide Concentrations Measured in the Soil Gas at the East Cell

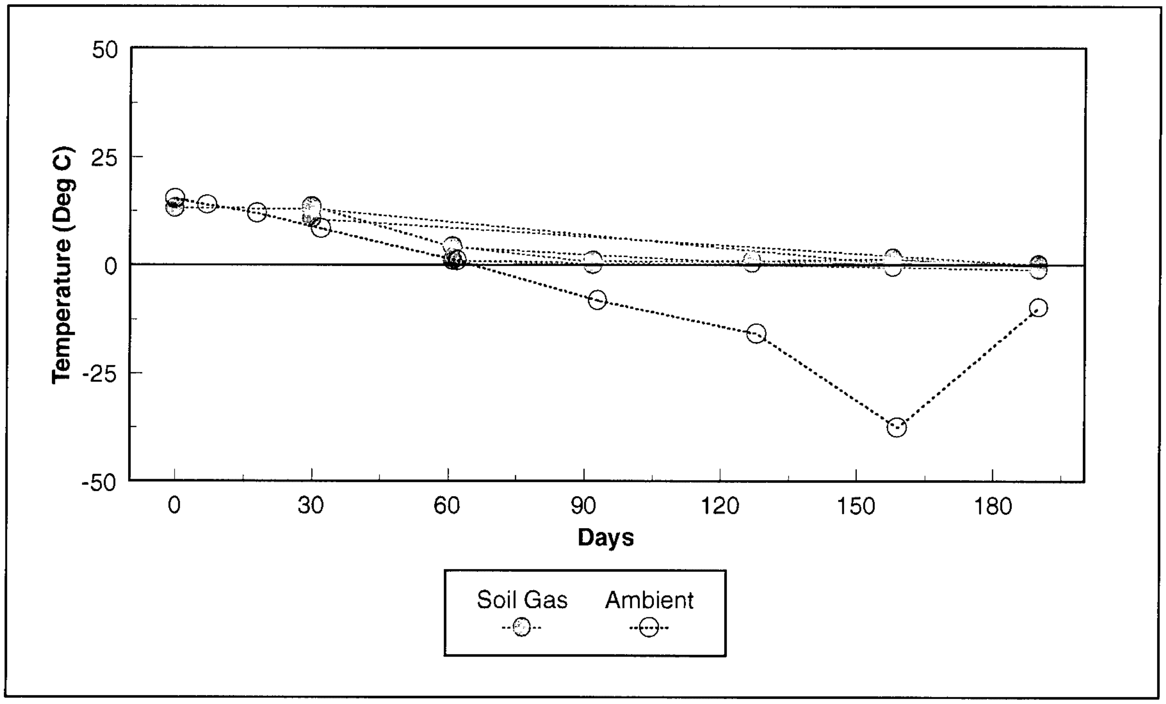


Figure 4-21. Soil Gas Temperatures Measured in the Shallow Vapor Probes at the East Cell

4.4.1 West Cell Operating Parameters

The daily flow rate for the SVE system was calculated from the daily monitoring data. A sample calculation is provided in Appendix C.3. Figure 4-22 presents the flow rate as a function of time during the pilot test. The flow rate averaged 132 scfm. The dips in the graph represent times when the system was shut down for sampling.

The exhaust gas from the West SVE unit was sampled periodically, and the results are presented in Figure 4-23. The TNMHC concentration averaged 20,000 ppmV throughout the pilot test. Previous SVE studies have demonstrated that SVE hydrocarbon extraction rates decrease over time, usually within one or two months. The steady rate of hydrocarbons removed in the West Cell indicates that the hydrocarbon source was not depleted during the test. The floating free product in the West Cell is the presumed source of VOCs.

The IAS system was evaluated on the basis of changes in dissolved oxygen (DO) concentration in the groundwater with time. Figure 4-24 presents these data. Generally, the DO did not increase significantly during the test period. DO measurements were not taken at Days 120 and 150 because the subzero temperatures prevented the use of the flow-through cell used to measure DO. The DO did increase in W-1 from 0.5 mg/L initially to 2 mg/L at Day 90. However, since monitor well W-1 was upgradient of the IAS system, the small rise in DO was probably not attributable to the IAS system.

The change in groundwater temperature from ambient was used to evaluate the effect of steam injection on the subsurface temperatures. The temperatures remained relatively constant until Day 180, when the temperature rose to above ambient at W-2 and W-3, as shown in Figure 4-25. The steam boiler was inoperable from Day 120 through Day 180, so the temperature increase is probably not attributable to the steam injection system. This temperature change may have been related to the increased soil temperatures observed in the West Cell. However, the monitor well closest to the steam injection wells (W-2) did show a 2° C increase at Day 60 compared with Day 0.

4.4.2 East Cell Operating Parameters

Figure 4-26 presents the East SVE flow rate as a function of time. The flow rate averaged 126 scfm. Again, the dips in the graph represent times when the system was shut down for sampling. Figure 4-27 presents the TNMHC and total BTEX results for the SVE exhaust gas analyses. The TNMHC concentration decreased at the beginning of the test and then increased during the last 120 days. Two explanations are given for this trend. First, the East SVE was shutting off daily from water collecting in the knockout tank during the first 60 days of operation. During that time, the vacuum was manually decreased as an attempt to decrease the amount of water collected by the system. The vacuum decrease was accomplished by bleeding ambient air into the system. This diluted the VOCs in the exhaust gas. Second, the water table declined steadily beginning in late September. As the water table fell, deeper portions of the hydrocarbon smear zone became drained of water, allowing air flow through the soil pores and allowing the stripping of VOCs.

Figure 4-28 presents the DO concentration in the groundwater from the East Cell over time. Generally, the DO remained around 1 mg/L during the pilot-scale test. The DO in W-6 and W-7 was measured at 4 mg/L at Day 180. These data are questionable, since this increase occured 190 days into the test. Figure 4-29 presents the groundwater temperatures in the East Cell. The temperatures remained steady during the study.

4.4.3 Air Permeability and SVE Zone of Influence

Three times (August, October, and December, 1993) during the Phase II pilot-scale test, a transient pressure performance test was conducted to measure the subsurface soils' permeability to air and to estimate the zone of influence of the SVE extraction well for both the East and West Cells. These tests were conducted at various stages of subsurface groundwater elevation to measure the change in the apparent air permeability and zone of influence with the declining water table. The data from these tests were fit with a one-dimensional, radial flow, homogeneous, and isotropic mathematical model. Data from these tests and calculations are provided in Appendix C.4.

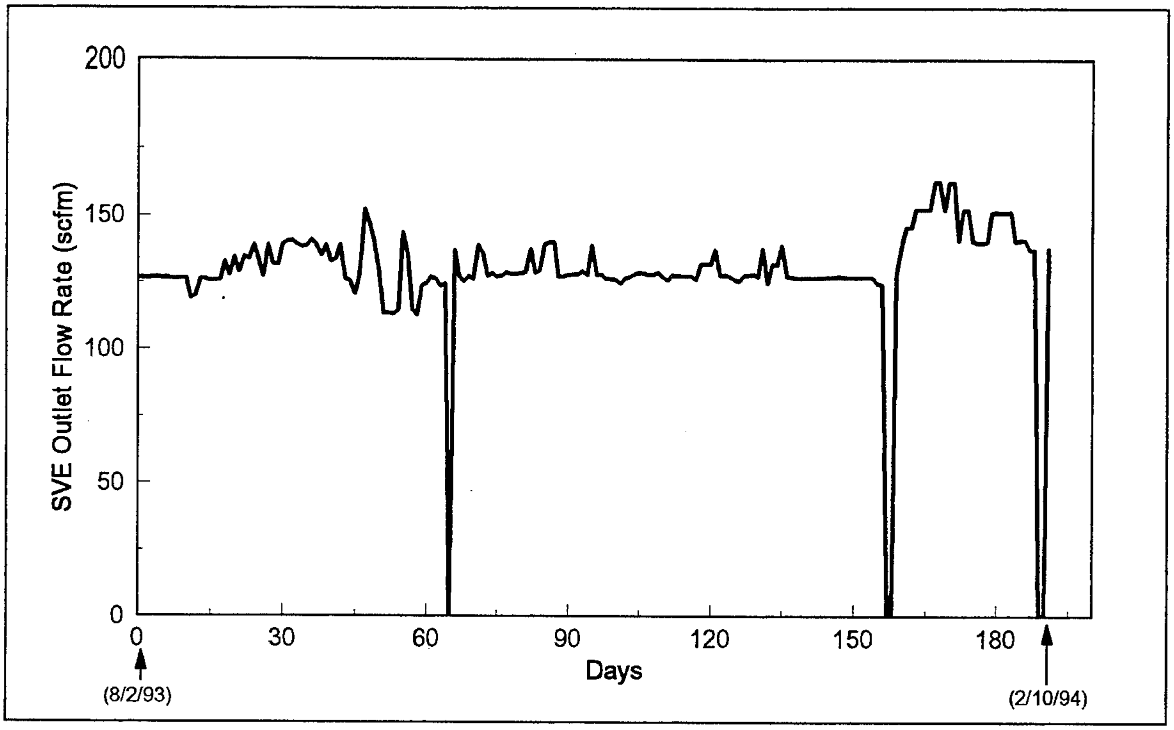


Figure 4-22. SVE Exhaust Gas Flow Rate During the Phase II Test for the West Cell

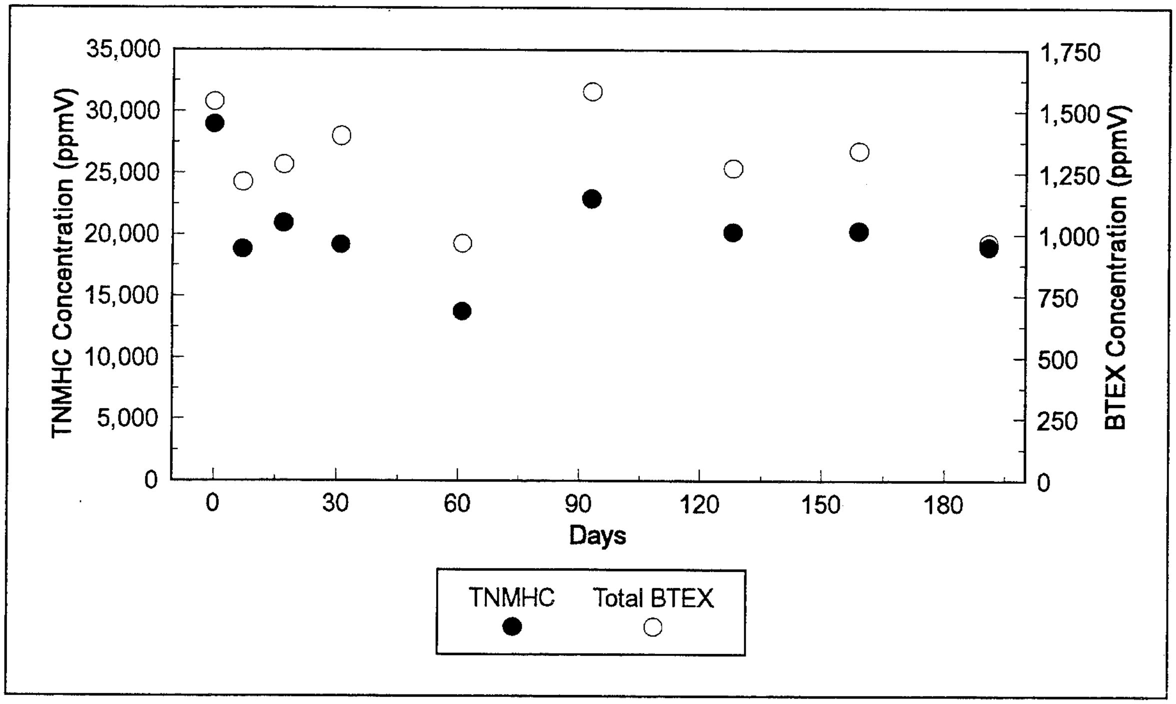


Figure 4-23. TNMHC and BTEX Concentrations in the SVE Exhaust Gas at the West Cell

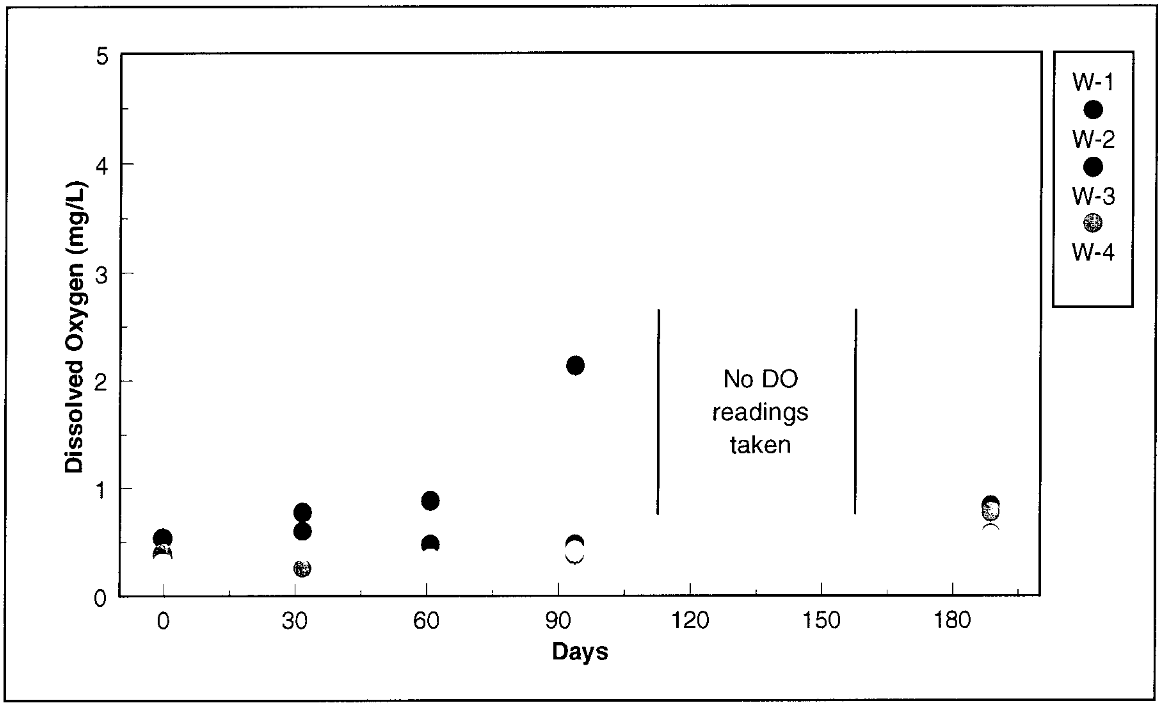


Figure 4-24. Dissolved Oxygen in Groundwater from the West Cell

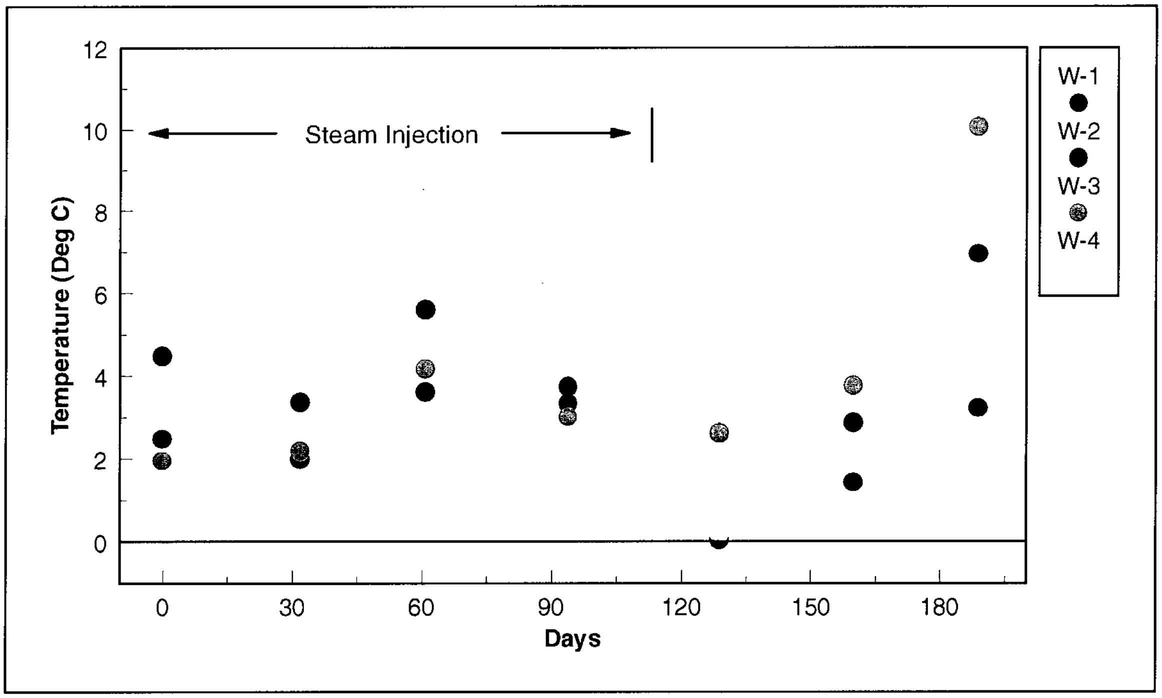


Figure 4-25. Groundwater Temperatures Measured at the West Cell

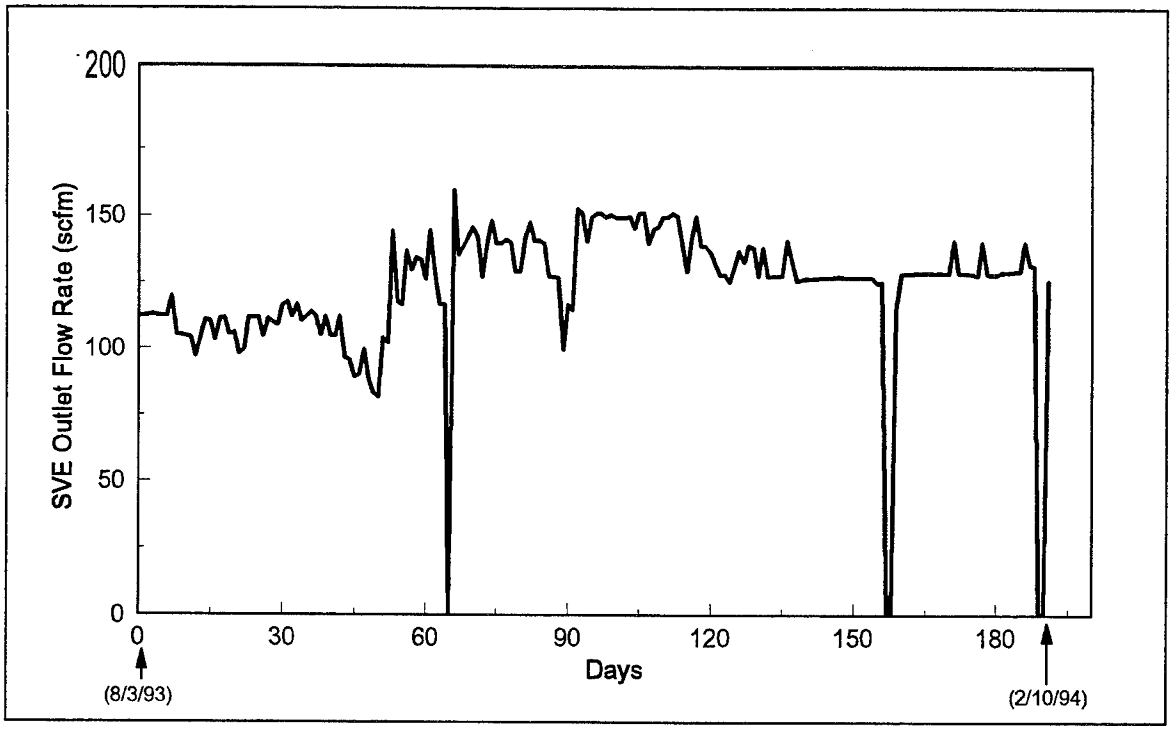


Figure 4-26. SVE Exhaust Gas Flow Rate During the Phase II Test for the East Cell

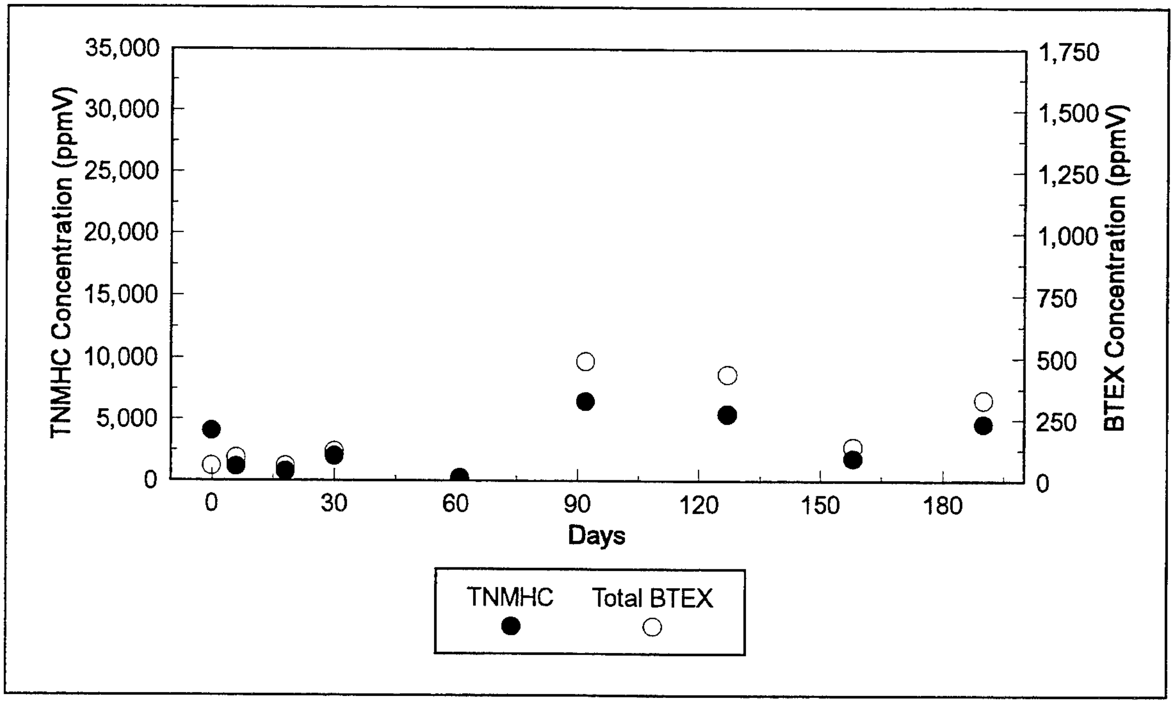


Figure 4-27. TNMHC and BTEX Concentrations in the SVE Exhaust Gas at the East Cell

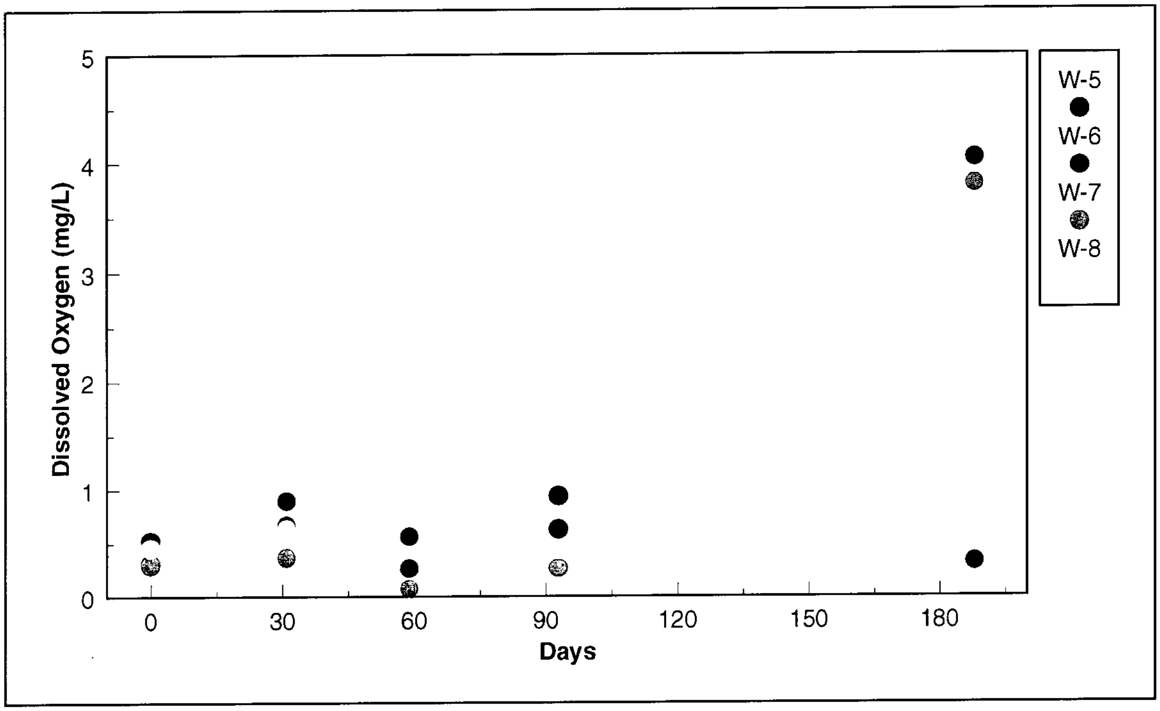


Figure 4-28. Dissolved Oxygen in Groundwater from the East Cell

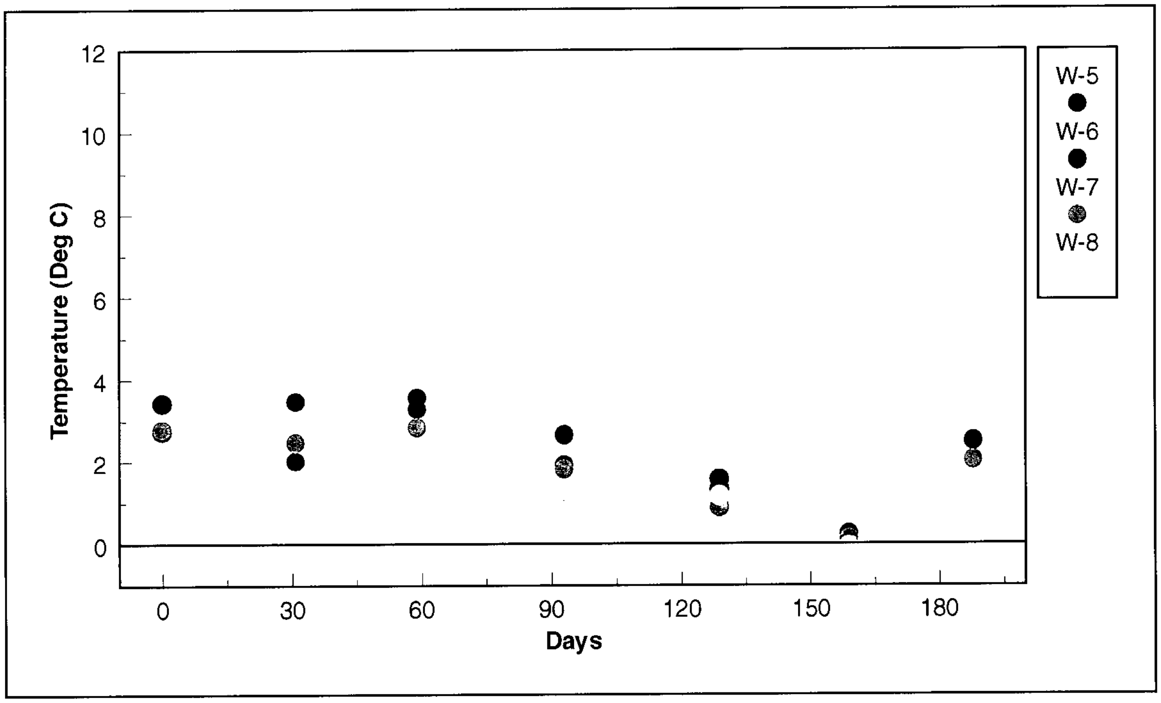


Figure 4-29. Groundwater Temperatures Measured at the East Cell

Additionally, steady-state pressure distribution data were collected and fit with a two-dimensional, radial flow, homogeneous, but nonisotropic model to provide a second estimate of the air permeability and radius of influence. This model allowed for differences in the vertical and horizontal permeabilities. Since there are two geologic units at the TS site, a sandy-silt zone and then sand and gravel, this model accounts for the site conditions (difference in air permeability with depth) better than the one-dimensional model does.

Transient Pressure Air Permeability Tests

A radial flow, homogeneous, and isotropic media model published by Johnson et al. (1993), was used to analyze the transient pressure test data. This model assumes that the change in pressure at a point is proportional to the log of time and that the plot of this relationship is a straight line. The slope of this line is inversely proportional to the air permeability of the soil, on the basis of the premise that a higher resistance to flow (i.e., low-permeable soils) requires more energy (i.e., more pressure to build up) before flow is induced toward the well.

August Test

On August 3, the first air permeability test was conducted on the East and West Cells. The depth to groundwater was approximately 12 ft bgl; therefore, the amount of SVE screen exposed was only 6 ft before a vacuum was induced (approximately 2 to 3 ft of screen was exposed after the SVE unit was turned on because of upwelling of the groundwater). Owing to a larger-than-expected influence by the West SVE system, which remained running during the initial test, the data for the East Cell could not be used for calculating the permeability and radius of influence for that area. However, observations collected on the East Cell provided additional data on performance of the West Cell SVE system. Data were collected from shallow vapor probes only (the deep probes had not yet been installed because of the high water table). Measurements were taken until there was negligible change (< 0.1 in. H_2O) in the subsurface pressure at each monitoring point.

Table 4-5 presents the permeabilities that were calculated for the West Cell.

Table 4-5
Calculated Air Permeability Coefficients From Transient Pressure Distribution Data in August 1993

Monitoring Point	Calculated Permeability Coefficient (cm^2)	Distance from SVE Well (ft)
West Cell		
V-1S	5.01×10^{-6}	14.1
V-2S	1.09×10^{-6}	8.6
V-7S	1.44×10^{-6}	37
V-8S	2.67×10^{-6}	43.3

The estimated air permeabilities ranged from about 100 to 500 darcys (1 darcy is equivalent to 10^{-8} cm^2). These values are much higher than the expected (typical) value for the sandy-silt soils that comprise the upper soil layer at the TS site. The principal reason for these values being skewed was the directional-flow effect created by the high water table and the vapor barrier. Because the unsaturated zone was thin and the soil surface in a 25-ft radius of the extraction well was covered, the flow and pressure fields established quickly outside the vapor barrier. The pressures at the shallow vapor probes approached steady-state in the first minutes of the test, and much of the early-time data could not be observed. Therefore, the data used to determine the permeability values represented the later stages of pressure field equalization; this caused the permeabilities to be overestimated by the model.

The equation by Johnson et al. (1993) predicted widely variable radii for the different monitoring points—from 33 to 126 ft. Owing to either heterogeneity in the subsurface or site conditions inconsistent with model assumptions, the predicted values were inconsistent with the idealized model. Vacuum measurements on monitor wells and vapor probes across the study area indicated that the radius of influence of the West SVE easily exceeds 100 ft.

October Test

On October 4, a second transient pressure air permeability test was performed. The depth to groundwater was between 17.3 and 18 ft. The tests were conducted on the two cells separately to prevent interferences between the SVE systems. Measurements were taken at both the shallow and the deep vapor probes.

The data were again reduced using Johnson's model; the calculated air permeabilities are provided in Table 4-6. The permeabilities calculated for the shallow soils were high for both cells, although the deeper permeabilities were in the typical range for sandy soils. The shallow permeabilities ranged from 84 to 120 darcys for the East Cell, and from 57 to 220 darcys for the West Cell. The deep permeabilities ranged from 52 to 117 darcys for the East Cell and from 58 to 71 darcys for the West Cell.

Table 4-6
Calculated Air Permeability Coefficients from Transient Pressure Distribution Data in October 1993

Monitoring Point	Calculated Permeability Coefficient (cm^2)	Distance from SVE Well (ft)
East Cell		
V-12D	9.45×10^{-7}	30.3
V-13D	9.62×10^{-7}	32.3
V-14D	9.42×10^{-7}	37.7
V-15D	8.91×10^{-7}	13.5
V-16D	5.29×10^{-7}	8.8
V-20D	1.18×10^{-6}	56.8
V-13S	1.20×10^{-6}	32.3
V-15S	8.46×10^{-7}	13.5
V-20S	1.10×10^{-6}	56.8
West Cell		
V-3D	6.26×10^{-7}	13.6
V-7D	7.08×10^{-7}	37
V-8D	5.85×10^{-7}	43.3
V-1S	5.75×10^{-7}	14.1
V-2S	7.66×10^{-7}	8.6
V-4S	2.20×10^{-6}	22.5
V-8S	8.75×10^{-7}	43.3

The data from the East Cell resulted in a calculated radius of influence ranging from 42 to 162 ft. The data from the West Cell indicated radii from 34 to 139 ft. From a review of the data, it is apparent that the model is much more sensitive to the distance a point is from the well than it is to the pressure response at that point. Overall, the maximum values predicted by this model for the radius of influence were confirmed by field observations.

December Test

On December 10, both SVE systems were shut off, and the test cells were allowed to return to ambient conditions. Separate permeability tests were conducted for the West and East Cells. Like the previous tests, data were collected at both shallow and deep depths for selected vapor probes until the pressure change at individual probes became negligible. Monitoring points were checked prior to starting the second test to ensure that the site had returned to ambient conditions.

Results of the permeability modeling are presented in Table 4-7. The permeabilities ranged from 34 to 63 darcys in the East Cell and from 77 to 96 darcys in the West Cell. The calculated permeability coefficients in the deep probes were in the typical range for medium to coarse sands and were very consistent; these data suggest that the deeper soils are homogeneous in the horizontal plane. The range of radius of influence values predicted from the model were 75 to 116 ft for the East Cell and 39 to 108 ft for the West Cell.

Table 4-7
Calculated Air Permeability Coefficients from Transient Pressure Distribution Data in December 1993

Monitoring Point	Calculated Permeability Coefficient (cm^2)	Distance from SVE Well (ft)
East Cell		
V-12D	6.26×10^{-7}	30.3
V-14D	6.23×10^{-7}	37.7
V-15D	3.42×10^{-7}	13.5
V-18D	4.90×10^{-7}	23.3
V-15S	6.97×10^{-7}	13.5
West Cell		
V-1D	7.70×10^{-7}	14.1
V-4D	9.57×10^{-7}	22.5
V-7D	8.38×10^{-7}	37
V-1S	1.04×10^{-6}	14.1
V-4S	1.43×10^{-6}	22.5
V-7S	1.05×10^{-6}	37

Three of the four shallow vapor probes monitored during the East Cell test showed almost no response during the test and were excluded from the results. The only reasonable explanation for this is that the majority of the air flow was occurring at depth on the East Cell and the pressure field did not develop in the shallow soils.

Summary of Transient Pressure Tests

From a comparison of the air permeability and radius of influence calculations, it is apparent that the West Cell is generally more permeable to air flow than the East Cell is. Overall, the TS site soil's permeability to air ranged from 50 to 100 darcys (values greater than 500 darcys were calculated but are considered in error because of the inability to capture early time data during the field permeability tests). The estimated permeabilities did not increase with increasing depth as anticipated, on the basis of soil lithology changes. This suggests that the model used to estimate the permeabilities could not account for the site conditions since the lower-zone sandy soils are known to be more permeable than the upper-zone silty soils. The early tests were undoubtedly heavily influenced by the vapor barriers and the shallow groundwater, which resulted in very rapid equalization of the pressure field; this condition caused permeability values to be overestimated. The final test in December represents the conditions that come closest to fitting the model (e.g., homogeneous and isotropic). The permeabilities determined for this test are assumed to be representative of air flow during the fall and winter period after the groundwater level declines.

Two-Dimensional Evaluation

To measure the anisotropy of the soils in the TS area, a two-dimensional, steady-state, homogeneous and anisotropic model by Shan, Falta, and Javandel (1992) was used. The model allows variability in the soil air permeability in the horizontal and vertical planes. This model is better suited for the TS site than the one-dimensional model because the depth of a lithologic change at the contact between silt gravelly sand was included as a boundary condition.

The model requires steady-state pressures recorded at two probes, whose vertical depths are different and are a sufficient distance from the extraction well. The model was used to compute the radial and vertical permeabilities to air from steady-state data collected in the West Cell during the Day-180 monitoring event.

The calculated radial (horizontal) permeability, k_r, was determined to be approximately 240 darcys, which is significantly higher than the one-dimensional model predicted. Appendix C.4 contains these calculations. However, the vertical permeability, k_z, was calculated to be only 11 darcys.

To evaluate the effect anisotropy has on the radius of influence, k_r and k_z estimates were used to predict the subsurface pressure distribution and flow field on the basis of the site conditions during February 1994. The flow net in Figure 4-30 presents the predicted flow lines and pressure contours. The model predicts that 70% of the flow to the extraction well is pulled from within a 50-m (164-ft) radius. These data are consistent with field observations and with the higher estimates obtained by the one-dimensional model. The theoretical radius of influence (not shown), within which 100% of the flow is contained, is predicted to extend 100 m (328 ft) from the well. Because the field data were collected with probes installed in the high-permeability sandy zone at a time when the groundwater level was at its maximum depth, the model prediction is optimistic and represents a best-case scenario. However, field observations confirm that an effective radius of influence of 130 ft or more is realistic for the POL area. More complex numerical models can be used to account for site-specific boundary conditions (such as the vapor barrier) and to optimize the design configuration of a full-scale SVE system.

4.4.4 Air Sparging Zone of Influence

A helium tracer test was performed in late August 1993 to determine the air sparging bubble pattern created by the IAS system. Separate tracer tests were performed for the shallow and deep sparge points. Eight vapor probes were installed at closely spaced intervals (2 to 4 ft) perpendicular and parallel to the groundwater flow direction (see Appendix C.5 for a schematic). A mixture of helium and air (5 to 10% helium) was sparged into the groundwater while the helium concentrations were monitored in the soil gas directly above the water table. The shallow and deep sparge points were submerged about 9 and 24 ft, respectively, during the test.

The steady-state results for the tracer test are presented in Table 4-8. Some of the results are at the instrument detection limit (IDL) of 0.01% so that little confidence is placed on the precision of the values.

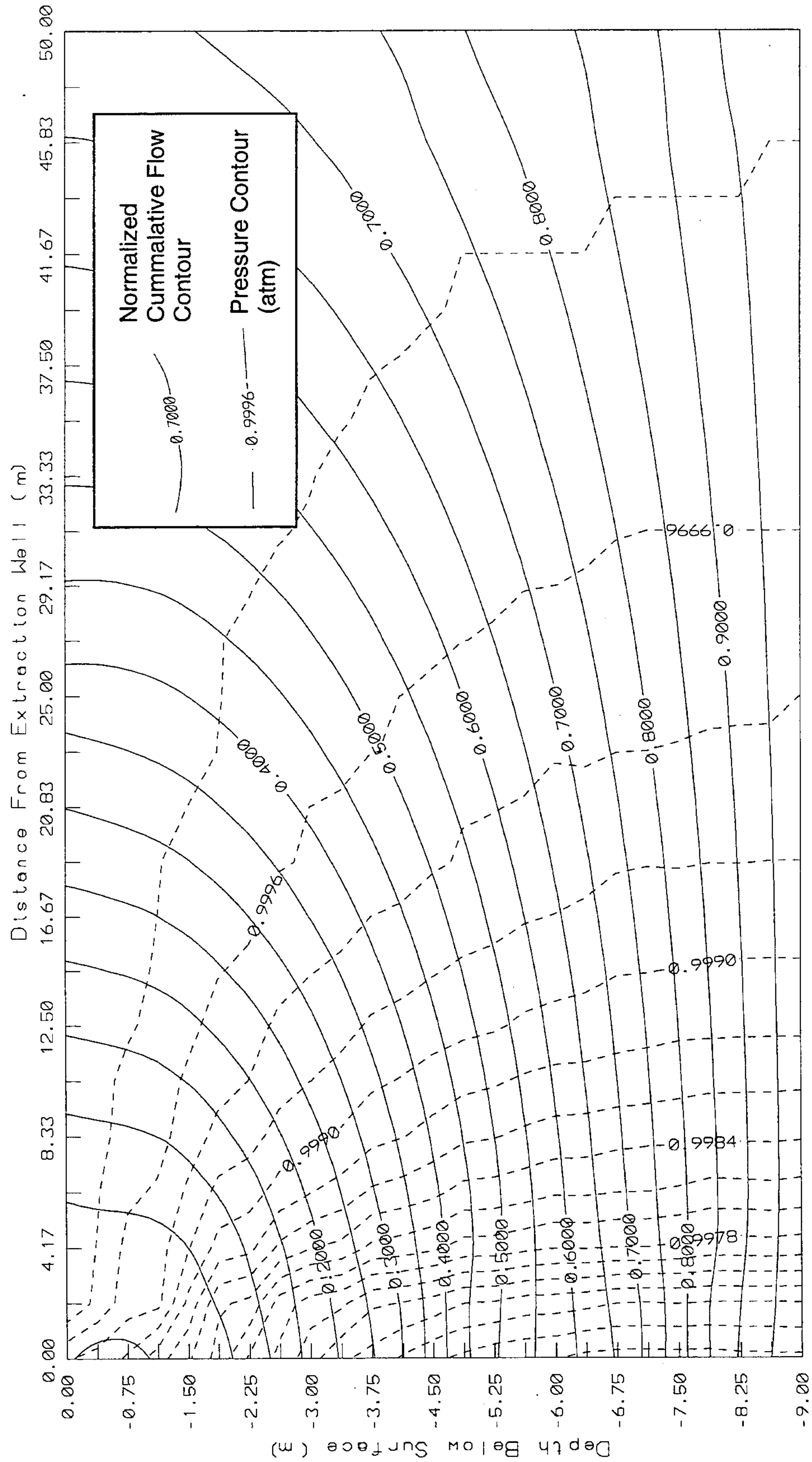


Figure 4-30. Typical SVE Flow Net in the West Cell During Phase II

However, a positive reading on the instrument was interpreted as an indication of helium presence at the vapor probe. On the basis of the data collected, the bubble zone created by the shallow sparge point extended a maximum of 2 to 4 ft parallel and 2 ft perpendicular to the direction of groundwater flow. If the midpoint of the range of detected values is used (3 and 1 ft) and the bubble zone is assumed to be symmetrical, the diameter of the bubble zone for the air sparging system was between 0.1 to 0.3 times the depth of submergence (9 ft). The data for the deep sparge point are difficult to interpret because the helium concentrations are within five times the IDL. Detection of helium that is a horizontal distance of 12 ft away from the deep sparge point suggests that the bubble zone may extend greater than 12 ft.

Table 4-8
Summary of Steady-State Helium Concentrations During the Air Sparging Tracer Test

Vapor Probe	Distance from A-8 (ft)	Helium Concentration (%)	
		Shallow Probes[a]	Deep Probes[b]
L-1	2	5	0.05
L-2	4	0.01	0
L-3	6	0	0.01
L-4	8	0	0.01
L-5[c]	12	--	0.04
T-1	2	0.23	0.03
T-2	4	0	0
T-3	6	0	0.02
T-4	8	0	0.02

Notes: [a] 9-ft submergence for sparge point. [b] 24-ft submergence for sparge point. [c] L-5 was not installed during the shallow test. L = Longitudinal, parallel to groundwater flow. T = Transverse, perpendicular to groundwater flow.

4.4.5 In Situ Respiration Tests

In situ soil respiration tests were conducted during the Day-60 and Day-150 sampling events in the West Cell and during the Day-150 sampling event in the East Cell. The respiration tests provided data used to estimate the biological degradation rate of hydrocarbons in the subsurface soils. To conduct the tests, the process components were shut off and the oxygen and carbon dioxide concentrations were monitored over a period of several days. The calculated oxygen uptake (depletion) rates were used to estimate hydrocarbon biodegradation rates based on the stoichiometric oxidation of a representative hydrocarbon, heptane. Appendix C.6 contains a description of the procedures and calculations used for the respiration tests.

The field results from the soil respiration tests are shown in Figures 4-31 and 4-32. The regression lines show the best-fit oxygen utilization and carbon dioxide evolution rates during each test. The calculated hydrocarbon degradation rate is also shown on each graph.

For the Day-60 respiration test in the West Cell, the highest estimated biodegradation rate was observed for V-1S (7.8 mg/kg/day). The degradation rates in the other probes ranged from 1.9 to 3.4 mg/kg/day. The lowest degradation rate was observed at V-6D. During the Day-150 test, the degradation rates ranged from 0 to 5.0 mg/kg/day. The rates observed at individual vapor probes were comparable between the two tests, except for V-8D, which dropped from 2 at Day 60 to 0 mg/kg/day at Day 150. The soil around this probe was frozen by Day 150, which may explain the decrease in biological activity. The biodegradation rates estimated in the West Cell were consistent with other field measurements (oxygen, carbon dioxide, and temperatures) and thus indicated that biological activity was occurring. The highest estimated biodegradation rates were observed in the vapor probes on the southwest portion of the West Cell.

Oxygen utilization rates, and therefore hydrocarbon degradation rates, at the East Cell were essentially zero during the Day-150 test. These data are consistent with other field measurements that showed little biological activity in the East Cell. The bacterial populations in the East Cell were high (up to 10^8 heterotrophic organisms), which indicates that there are indigenous bacteria at the site; since there is little contamination present, biological activity was limited.

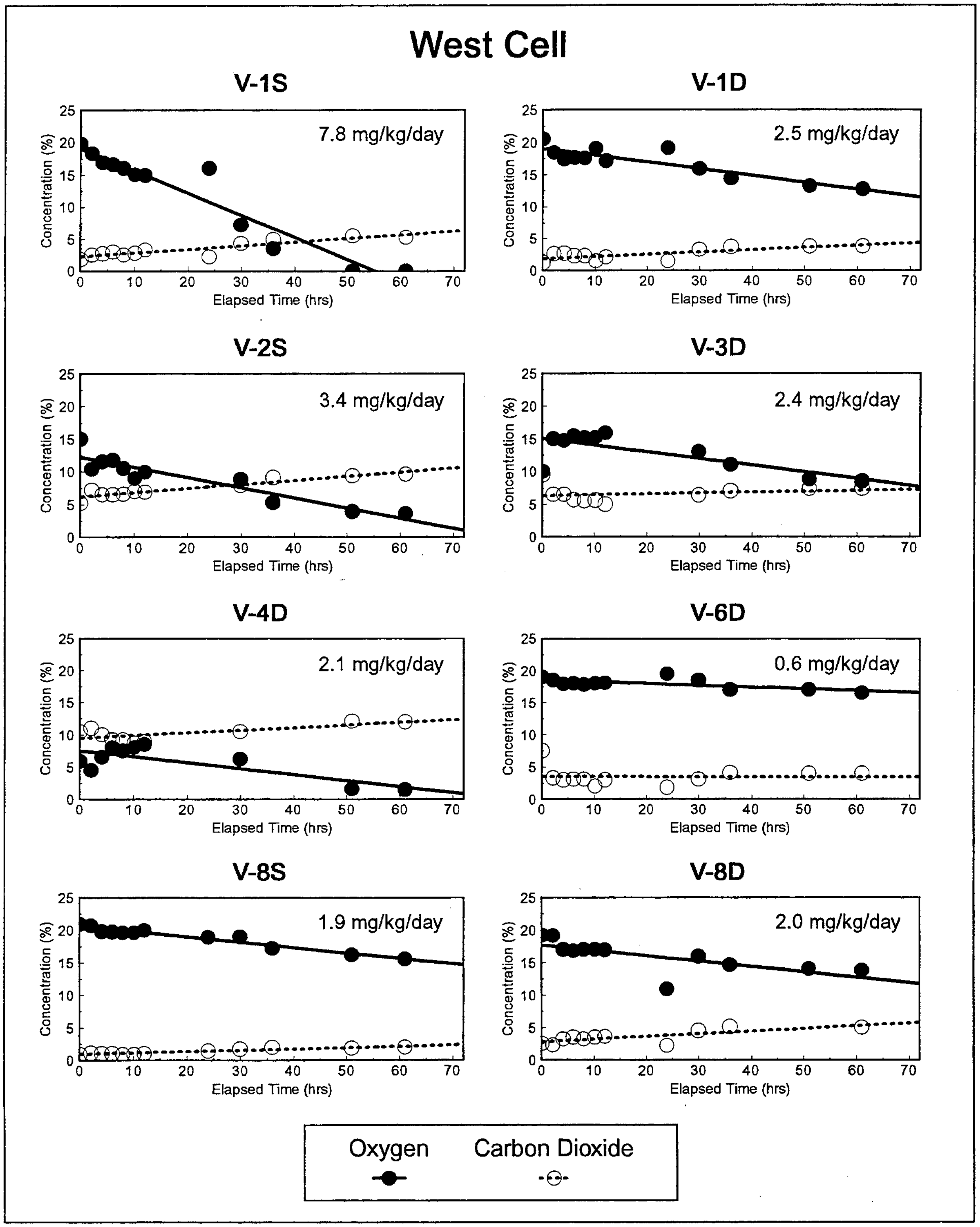


Figure 4-31. Oxygen Utilization, Carbon Dioxide Production, and Estimated Hydrocarbon Degradation Rates During the Day-60 Respiration Test in the West Cell

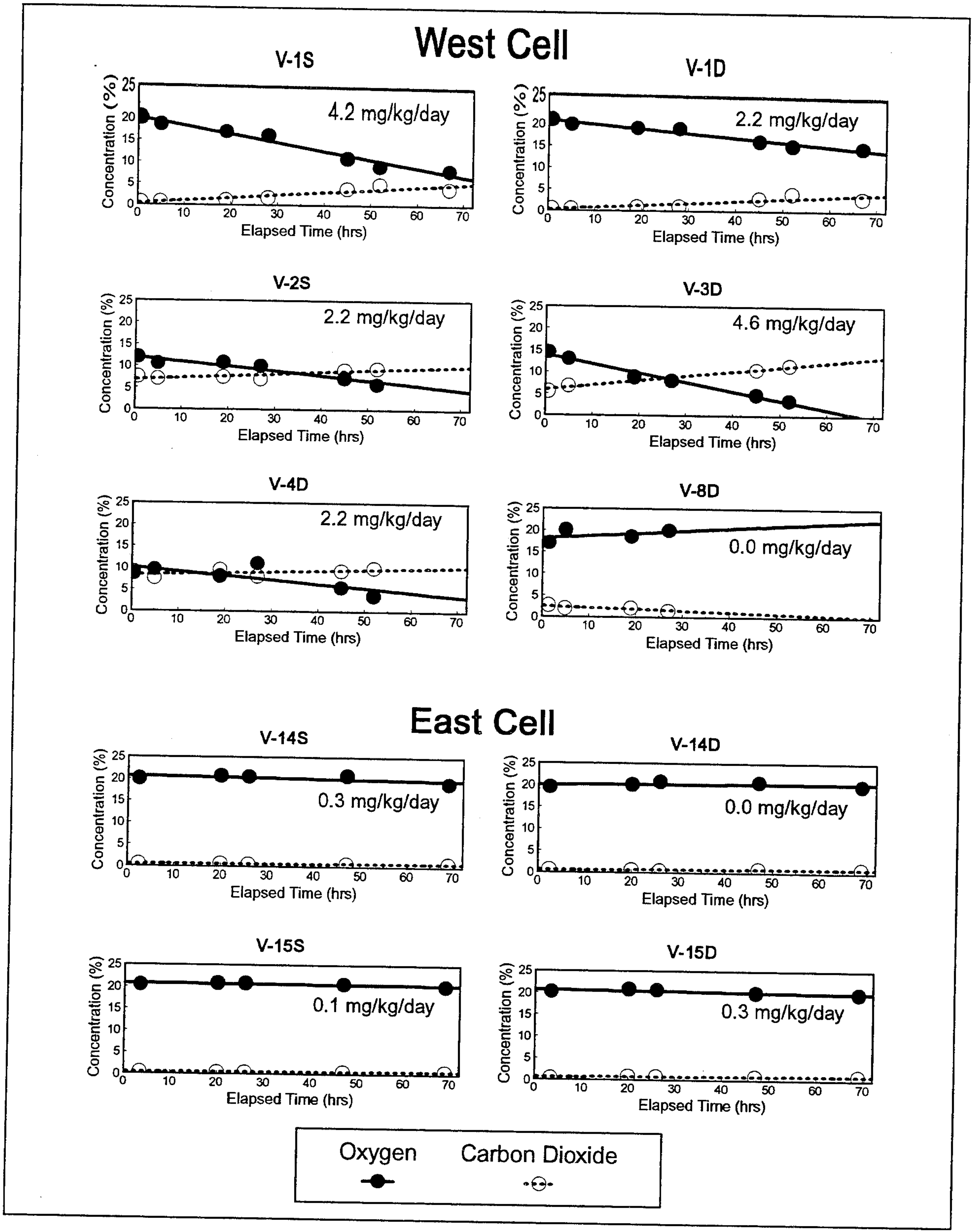


Figure 4-32. Oxygen Utilization, Carbon Dioxide Production, and Estimated Hydrocarbon Degradation During the Day-150 Respiration Test

Section 5
LNAPL RECOVERY TESTING AND RESULTS

Since little was known of the horizontal extent of free-floating hydrocarbon product or its seasonal distribution in early 1992 when the TS was designed, the pilot-scale tests focused primarily on the remediation of vadose-zone contaminants and, to a lesser degree, on the remediation of groundwater. However, free-product surveys, baildown well tests, and free-product skimming tests have been conducted on three separate occasions in the Galena POL Tank Farm area to evaluate the feasibility of LNAPL recovery using skimming techniques. The first two phases of this test program where conducted during the summer and fall 1992-1993 during the normal high-water table portion of the annual hydrological cycle related to the rise of the Yukon River. A third phase of LNAPL recovery testing was conducted in April 1994 during the winter low-water table period. The following section summarizes the testing activities and results from the LNAPL recovery tests. Refer to Figure 4-1 for locations of the wells tested during this program. Well measurement data and elapsed time plots of floating product and water levels are included in Appendix D.

5.1 Phase I Recovery Testing (September 1992)

5.1.1 Activities

During the 1992 Galena field season, two 6-in. diameter hydrocarbon recovery wells (05-RW-01 and 05-RW-02) and a number of 2-in. monitoring wells were installed in the POL. These wells were located in areas where floating product had been observed during previous investigations (USAF, 1991, 1993e). Long-duration (3-day) baildown tests were conducted on recovery well 05-RW-01 and a nearby 2-in. monitoring well (05-MW-10). The baildown test procedure involved rapid removal of the floating product in the well using a standard, bottom-valve Teflon® bailer. Elapsed recovery time was recorded beginning at the moment the final bail was removed. During the recovery period, periodic measurements were taken for water level, product level, and elapsed time.

A pneumatic, hydrocarbon recovery system (Clean Environment Engineers, SOS product-only skimming system) and a portable air compressor were purchased and shipped to Galena to conduct field recovery tests. This skimming system was tested briefly at the close of 1992 field activities.

5.1.2 Results

Both wells displayed similar water and product level behavior during the baildown tests. An LNAPL layer, which had an apparent thickness of 1.5 ft in the wells, was nearly completely removed by bailing at the start of the test. Following baildown, the free product recovered slowly throughout the monitoring period. Results for baildown tests on wells 05-MW-01 and 05-MW-10 are shown in Figures 5-1 and 5-2.

Analysis of the data focused on determining the inflection point on the water level versus time recovery curve. According to Gruszczenski (1987), the actual formation thickness corresponds to this inflection point. In other words, after the product level in the well is reduced by pumping or bailing, the water level first rises in response to the removal of the weight of the former floating-product layer, and then falls as the floating-product layer gradually recovers into the well. The point where the water level begins to fall is termed the inflection point; this point is considered to represent an accurate estimate of the LNAPL thickness in the formation. Generally, the apparent hydrocarbon thickness observed in a well is about 70% to 95% greater than the actual formation thickness estimated at the inflection point.

For recovery well 05-RW-01, an inflection point in water levels was observed almost immediately upon cessation of bailing. The product thickness corresponding with this inflection point was 0.15 ft. Monitor well 05-MW-10 showed similar recovery behavior and had an estimated formation product thickness of 0.03 ft. Because the magnitude of the water level change in both wells was so small and

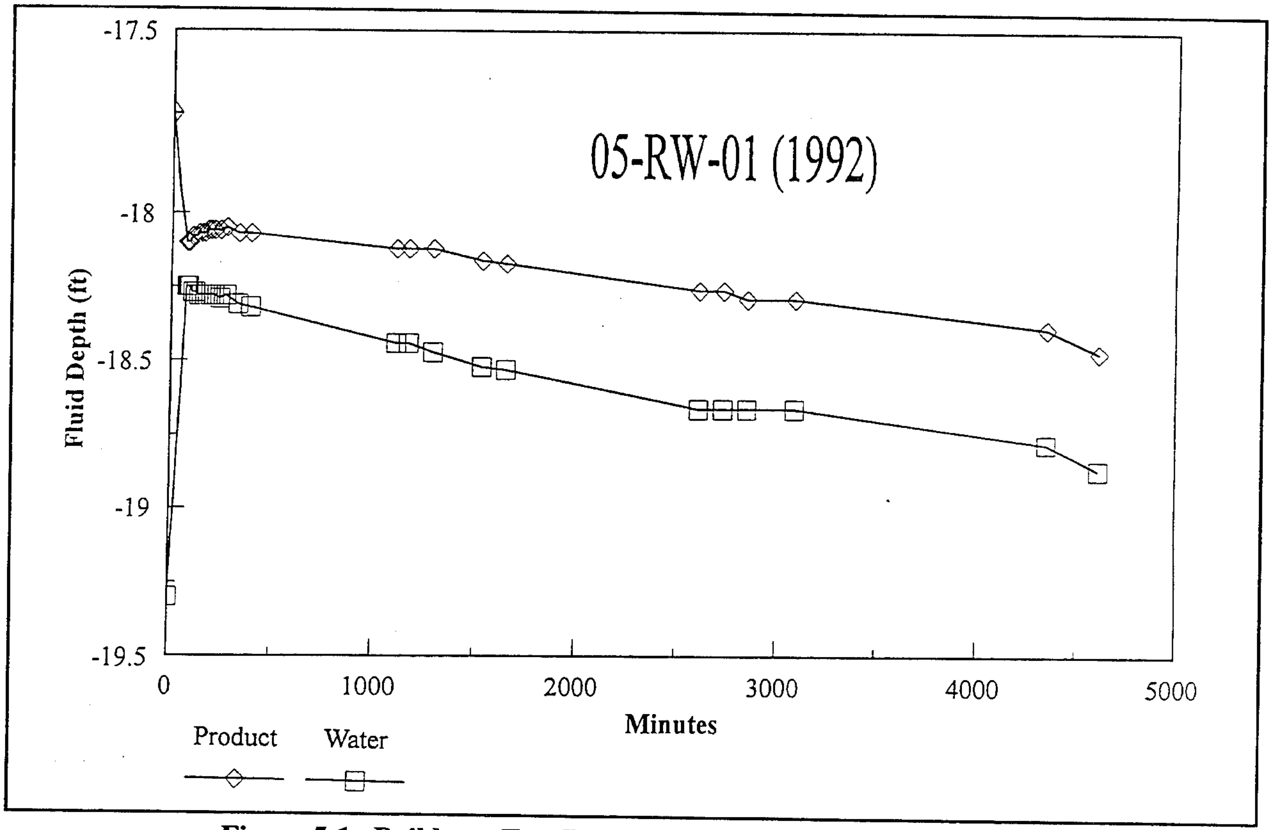


Figure 5-1. Baildown Test Results for 05-RW-01 (September 1992)

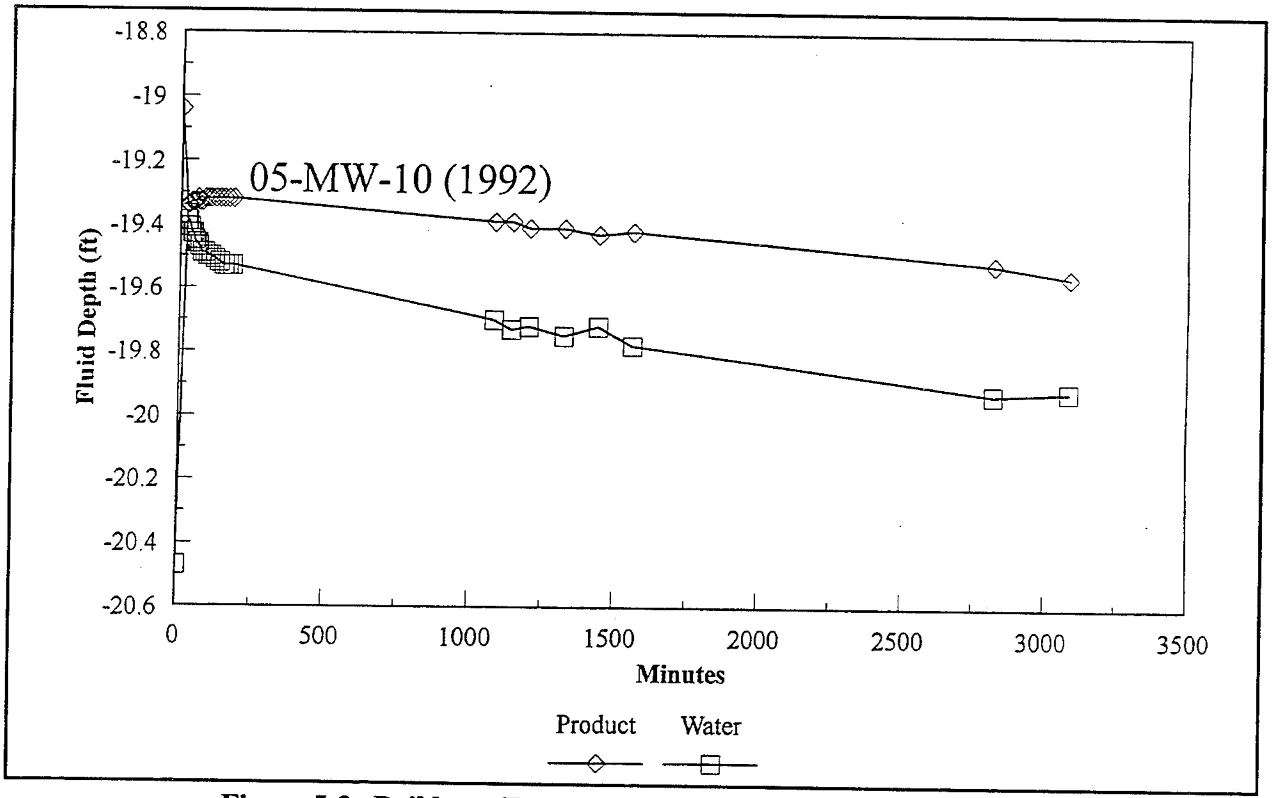


Figure 5-2. Baildown Test Results for 05-RW-10 (September 1992)

occurred so rapidly, there is some uncertainty as to the validity of the formation product thickness estimates.

5.2 Phase II Recovery Testing (July 1993)

5.2.1 Activities

In July 1993, additional baildown and skimming tests were conducted in the POL area. The primary objectives were twofold: 1) to determine the recharge rate of LNAPL from the formation into the well, and 2) to determine the true product thickness in the formation. Baildown tests were performed on four wells in the POL area (05-RW-1, 05-RW-2, 05-MW-04, and 05-MW-10) and one well in the Million Gallon Hill area (09-MW-08). Skimming tests were performed at three of these wells (05-RW-01, 05-RW-2, and 05-MW-10).

Baildown Tests

Baildown testing was performed in a manner similar to the previous tests. In the case of 09-MW-08, 05-MW-10, and 05-MW-04, the baildown test was performed first, which is the conventional method. The water and hydrocarbon levels in the well were then allowed to recover over a 3- to 10-day period; water and product levels were monitored throughout the recovery period. For recovery wells 05-RW-1 and 05-RW-2, skimming tests were performed initially. The skimmer system effectively bailed out all the LNAPL in the well; the pump was then shut off and the recovery of water and hydrocarbon were monitored over time.

Skimming Tests

The SOS Recovery System used for the skimming tests is shown schematically in Figure 5-3 (the recovery system actually used differs slightly from the schematic in that there is no recovery pump inside the control panel; rather, a downhole pump is placed just above the SOS skimmer assembly). Operation of the SOS skimmer pump reduces the product level in the well below the product level in the formation. The manufacturer claims that the skimmer pump can reduce product levels in a well to 0.3 in. (our experience indicates that the equipment is most efficient with at least 1 in. of standing product in the well). The major system components are a 2- or 4-in. skimmer assembly, a pneumatic pump, and a pneumatic-actuated control panel. The skimmer assembly is suspended in the well by polypropylene rope. A portable electric generator (23kW) and a 2-hp air compressor were used to power the system.

Prior to installation of the SOS pump assembly into the well, an oil-water interface probe was used to manually measure the floating product thickness. Product removed from the well was collected in a bucket and measured periodically using a 1000-mL graduated cylinder. Skimmer pump cycle times were adjusted at the control panel to maintain a minimum product thickness in the well. The pump was initially set to the low rate and then optimized by adjusting the cycle time to match the skimming rate with the well recharge rate.

5.2.2 Results

Baildown Results

The results of the baildown tests are listed in Table 5-1. The "Time = 0 Thickness" is the product thickness in the well immediately after baildown of the well. Also presented is the product thickness at various elapsed times (1, 6, 24, 36, and 48 hours) following baildown. In parentheses is the percentage of the original apparent product thickness (before the baildown test). Only one well (05-MW-10) showed a high rate of recharge; this well recovered 44% of its original product thickness within 1 hour.

Figures 5-4 and 5-5 present baildown/skimming results for wells 09-MW-08 and 05-RW-01, respectively. Unfortunately, we were never able to clearly observe the inflection point in any of the baildown/skimming tests that could be used to estimate product thickness in the formation. Possible explanations for the observed trends are as follows:

- For wells 05-RW-01 and 05-RW-02, the SOS skimming system did not recover LNAPL quickly enough to produce a distinctive drop in the product thickness; therefore, the water levels did not rise quickly in response to the product removal step.

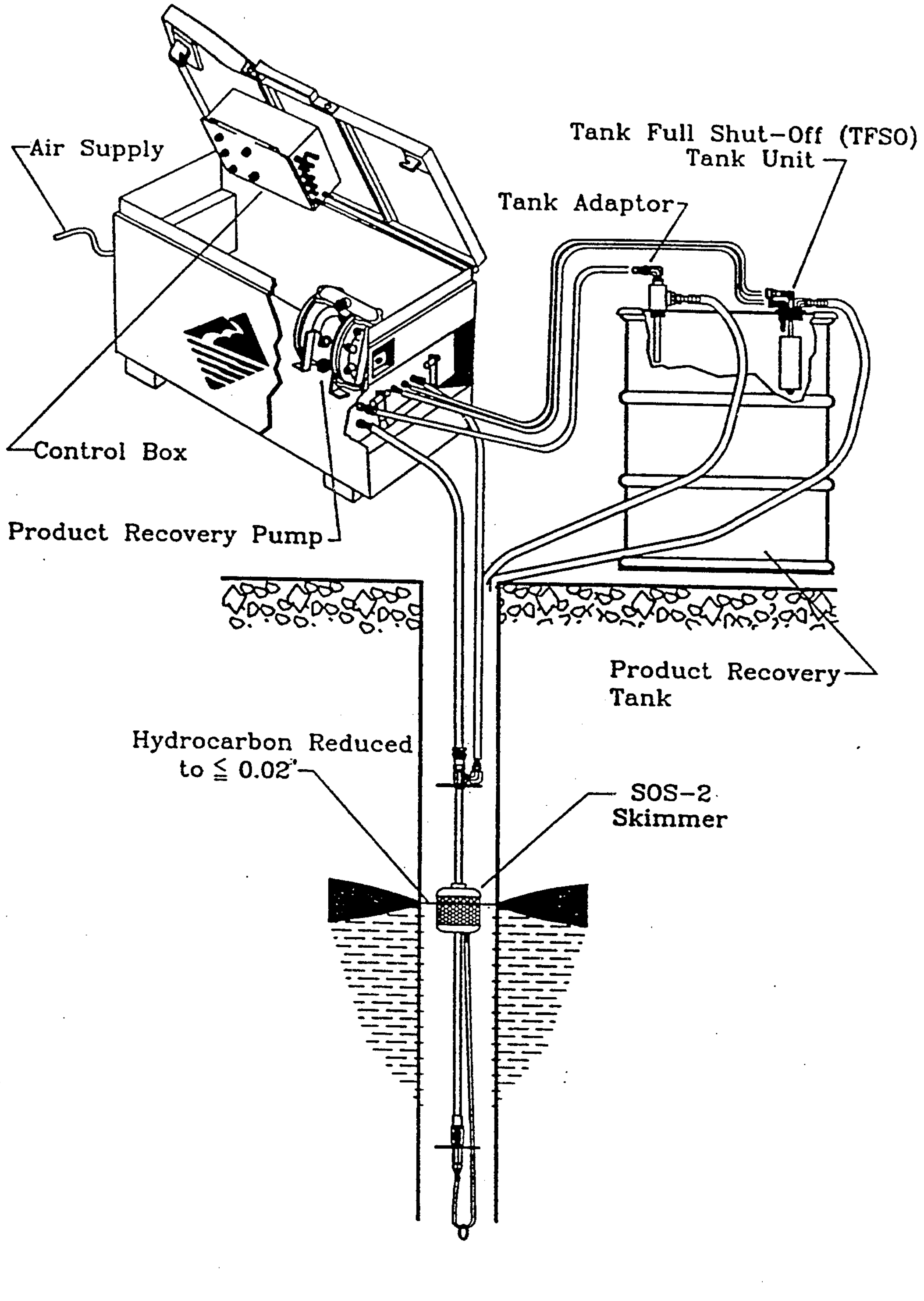


Figure 5-3. Schematic of SOS Product-only Recovery System

Table 5-1
Phase II Hydrocarbon Recovery Summary (Summer 1993)

Well ID	05-RW-01	05-RW-02	05-MW-04	05-MW-10	09-MW-08
Initial Measurements					
Original Product Level	13.73	13.48	13.42	15.63	18.68
Original Water Level	15.73	13.65	14.00	16.79	19.68
Original Product Thickness	2.00	0.17	0.58	1.16	1.00
Original Volume	2.94 gal.	0.25 gal.	0.09 gal.	0.19 gal.	0.16 gal.
Recovery Results					
Time = 0 Thickness	0.00	0.02	0.00	0.00	0.01
1-Hour Thickness	0.00 (0.0%)	0.02 (11.8%)	0.00 (0.0%)	0.50 (43.9%)	0.07 (7.0%)
6-Hour Thickness	0.02 (1.0%)	0.03 (17.6%)	0.01 (1.7%)	0.80 (69.0%)	0.15 (15.0%)
24-Hour Thickness	0.09 (4.5%)	0.03 (17.6%)	0.01 (1.7%)	0.85 (73.3%)	0.30 (30.0%)
30-Hour Thickness	0.10 (5.0%)	0.03 (17.6%)	0.00 (0.0%)	0.92 (79.3%)	0.30 (30.0%)
48-Hour Thickness	0.25 (12.5%)	0.01 (5.9%)	0.00 (0.0%)	0.91 (78.4%)	0.32 (32.0%)
Estimated Formation Thickness	0.40	0.03	0.12	0.23	0.20
Skimming Results					
Well Skimmed?	Yes	Yes	No	Yes	No
Recovered Volume	5.23 gal. (178%)	0.16 gal. (64%)	--	0.46 gal. (243%)	--

Note: All results in feet.

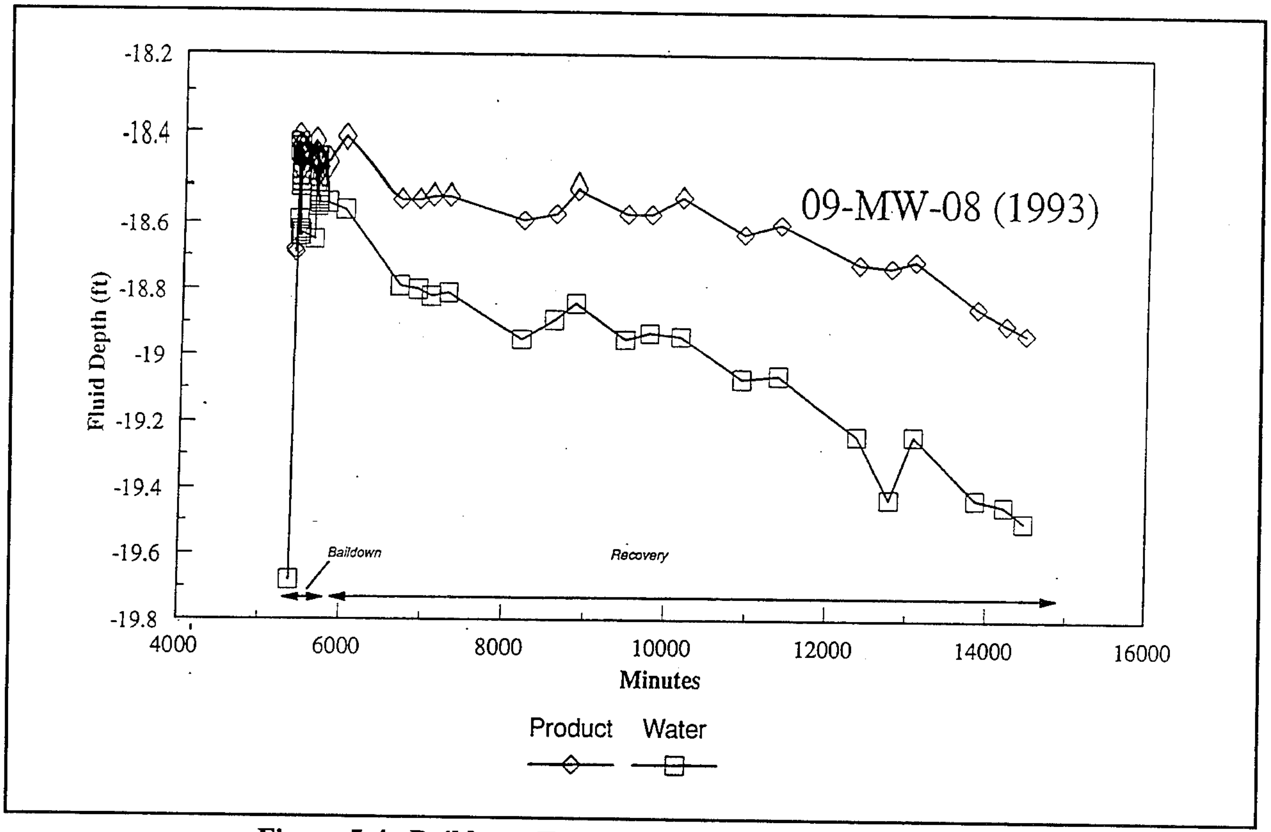
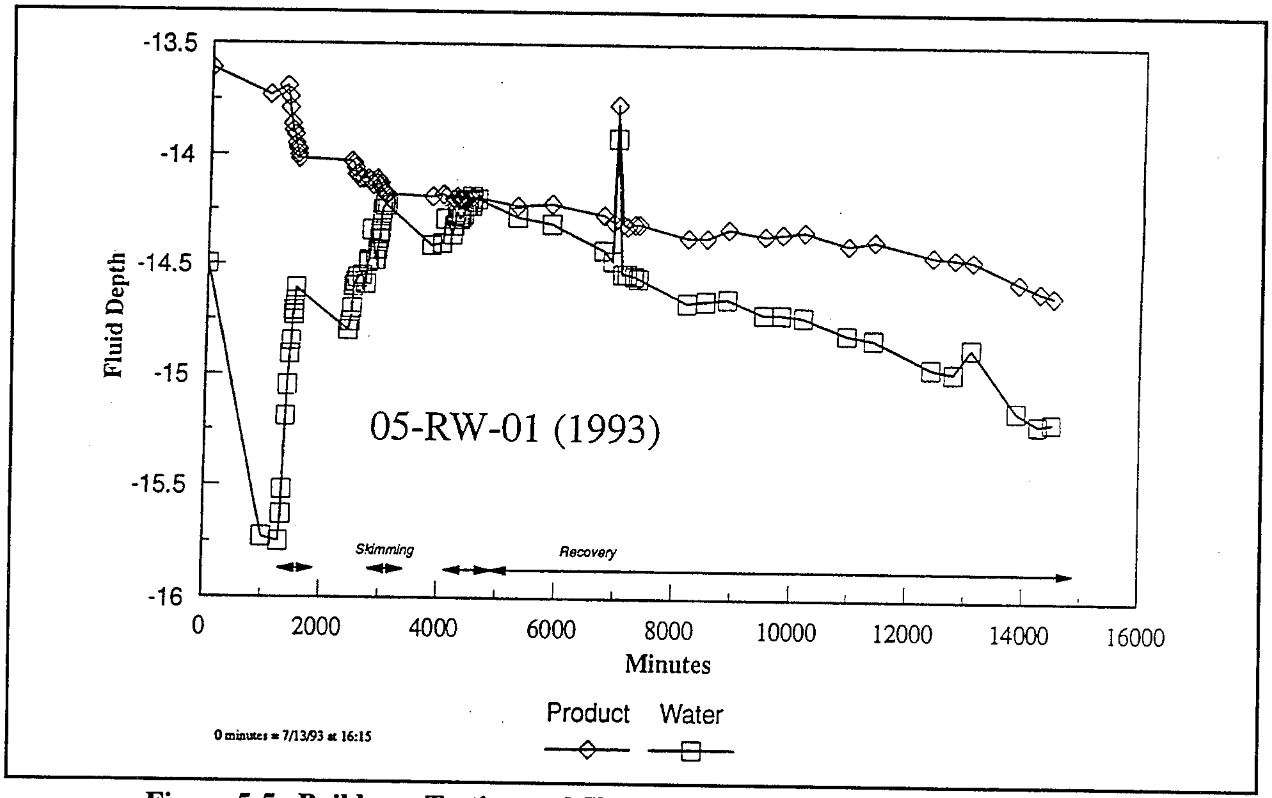


Figure 5-4. Baildown Test Results for 09-MW-08 (July 1993)



0 minutes = 7/13/93 at 16:15

Figure 5-5. Baildown Testing and Skimming Results for 05-RW-01 (July 1993)

- For the other wells, a rapid recharge of water levels occurred immediately following baildown without the characteristic gradual rise and fall of water levels typically observed; this is explained by the rapid water recharge into the well screens from the deeper portion of the aquifer, which consists of more permeable sand and gravel strata. The free product, on the other hand, recharged from the silty strata at a much lower rate.

- For all wells, the water levels gradually declined throughout the static and recovery segments of the test; this reflects the normal regional decline of the water table caused by falling Yukon River levels. This decline complicated analysis of the observed baildown results.

- Finally, the tenacious behavior of silty materials in the upper portion of the unconfined aquifer prevented adequate recharge of LNAPL into the wells; the hydrocarbons were essentially bound within the pore spaces of the silty strata above the capillary fringe zone.

Testa and Paczkowski (1989) presented an alternate, conservative method for determining the formation thickness from monitor well observations. Essentially, this method states that the actual formation thickness is estimated by multiplying the observed thickness by (1 - specific gravity$_{LNAPL}$). The "estimated thickness" values in Table 5-1 were calculated using this method, assuming an LNAPL specific gravity of 0.8 g/cm^3. Values for estimated true product thickness by this method ranged from 0.03 to 0.4 ft.

To predict the recovery rate of the SOS system, we used the baildown results to predict recovery rates. As shown in Table 5-1, the product thickness in recovery well 05-RW-01 recovered 0.015 ft in 6 hours. For this 6-in. diameter well, this converts to a recharge rate of 0.116 gal./day (42 gal./year), if operated continuously. Monitor well 05-MW-10 (2-in. diameter) had the highest rate of recovery (2 gal./day) and the highest relative recovery volume (2.4 times the amount initially present) of the five wells tested. However, the recovery estimates should be viewed with caution for the following reasons:

- The recovery rate may decrease over time as the product in the formation is removed;

- The skimmer system cannot be operated continuously because it requires periodic maintenance and downtime; and

- Recovery rates are likely to change in response to seasonal changes in water levels (higher rates are expected when the groundwater table drops).

Skimming Results

The results of the Phase II skimming test at 05-RW-01 are presented in Figure 5-5. Skimming occurred during three episodes over a three-day period. On each occasion we were not able to reduce the extraction rate low enough to match the recovery rate. Therefore, the product thickness continued to fall until it was essentially zero by the third day. Both the product and water levels in the wells continued to drop during the seven-day recovery period—this was caused by the regional decline in the groundwater level. The recovery system was also tested at recovery well 05-RW-02 and monitor well 05-MW-10 with similar results: the system gradually reduced the product thickness to zero and then continued to recover what little product entered the well from the formation over time.

5.3 Phase III Recovery Testing (April 1994)

The previous tests were unable to define the true LNAPL thickness precisely at these sites because of hydrologic conditions that exist during the summer and fall months. The tests were hindered by groundwater in or near the base of the upper, silty horizon of the unconfined aquifer. Observations of LNAPL apparent thicknesses made in monitor wells during the Phase II SVE pilot-scale test indicated that free product drains from the upper portion of the aquifer and capillary fringe and accumulates above the water table during the winter months (refer to Figure 4-9).

5.3.1 Activities

During April 1994, a product thickness survey, baildown tests, and a skimming/recovery test were conducted to evaluate the following items:

- The apparent product thickness in all monitoring wells present at the Galena Airport POL Tank Farm and Million Gallon Hill areas;
- The true product thickness in the formation according to baildown/recovery tests;
- The recharge rate of LNAPL from the formation into monitoring and recovery wells; and
- The skimming ability of the SOS system during winter operation.

Product Thickness Survey

Prior to selection of the wells to be included in the baildown/recovery test program, a product thickness and water level survey was conducted on monitoring and recovery wells in the POL and Million Gallon Hill areas.

Baildown Testing

Phase III baildown/recovery tests were performed on five wells, including four wells at the POL area (05-MW-04, 05-RW-02, 05-W-2, and 05-MW-07) and one from the Million Gallon Hill site (06-MW-04). Prior to bailing, a pressure transducer was installed about 5 ft below the water level. A data logger monitored normalized water levels in the wells prior to the test, during baildown, and throughout the first day of the recovery period. These measurements used a logarithmic program to record levels during recovery.

Skimming Test

For Phase III, we originally intended to measure LNAPL extraction/recovery rates for at least two wells, including both a 6-in. recovery well and a 2-in. monitor well. However, problems caused by freezing of liquids in the skimmer discharge pipe and failure of a pump component prevented testing of the 2-in. well. For the test on the recovery well, we attempted to match the extraction rate to the recovery rate observed for the baildown test on that well.

5.3.2 Results

Product Thickness Survey Results

Product thickness measurements were made on 27 wells in the POL Tank Farm and Million Gallon Hill areas. The results of the product level survey are presented in Table 5-2. Other wells where measurements are not reported contained minimal amounts of product, could not be located because of snow accumulation, or groundwater levels had fallen below the total depth of the well.

Skimming Test Results

Skimming was performed on recovery well 05-RW-02 because it contained the greatest LNAPL thickness of the two recovery wells. Two serious problems developed during the skimming test. After a few hours of operation, the extraction rate from the well dropped significantly because liquids froze within the pump discharge hose. This problem was corrected by removing and defrosting the pump assembly. Shortly afterwards the pump failed, which prevented any further skimming tests. A bottom bobbit valve within the pump housing had malfunctioned so that product could not be removed from the well. Prior to pump failure, the system removed nearly 5 gal. of floating product from the well, which reduced the product level in the well by just over 1 gal. Unfortunately, the pump failed before the extraction rate could be adequately matched to the product recharge rate. However, the early success in recovering product from the well and the rapid recovery of the well are indicators that product recovery is feasible during winter months. Table 5-3 summarizes the results of the skimming test on recovery well 05-RW-02.

Table 5-2
Phase III LNAPL Thickness Survey (Winter 1994)

Date	Time	Well ID	Product Depth (ft)	Water Depth (ft)	Product Thickness (ft)	Comments
4/13/94	1500	05-MW-04	27.7	30.08	2.38	
4/13/94	1512	05-MW-03	30.24	30.85	0.61	
4/13/94	1530	05-MW-02	No product	32.01	0	
4/13/94	1547	05-MW-37	No product	No water	0	Dry well 28.50 depth to bottom
4/13/94	1620	05-MW-05	27.69	27.69	Sheen	Sheen
4/13/94	1640	05-MW-01	27.86	30.19	2.33	
4/13/94	1655	05-MW-10	28.88	No water	1.52	30.40 depth to bottom
4/13/94	1705	W-5	No product	33.03	0	Treatability study well
4/13/94	1710	05-MW-01	28.41	29.64	1.23	29.9 depth to bottom
4/13/94	1730	05-MW-08	No product	27.93	0	
4/13/94	1740	05-MW-09	No product	No water	0	28.3 depth to bottom
4/13/94	1745	05-MW-11	No product	No water	0	27.6 depth to bottom
4/13/94	1800	05-MW-13	No product	No water	0	27.6 depth to bottom
4/13/94	1805	05-MW-12	No product	No water	0	24.9 depth to bottom
4/13/94	1815	KV-1	No product	No water	0	23.4 depth to bottom
4/13/94	1820	KV-6	No product	27.95	0	
4/13/94	1828	6" Pump Well	No product	26.71	0	
4/13/94	1830	KV-2	No product	27.13	0	
4/13/94	1835	KV-4	No product	27.84	0	
4/13/94	1840	KV-3	No product	22.84	0	23.10 depth to bottom
4/13/94	1845	05-MW-06	No product	27.38	0	Has a transducer in it
4/13/94	1850	KV-5	No product	28	0	
4/14/94	1750	05-MW-15	--	--	--	Could not open, well cap damaged
4/14/94	1800	05-MW-14	--	--	--	Could not locate, covered by 2 in. of ice
4/14/94	1820	05-MW-38	--	--	--	Could not locate under 2 ft of snow
4/14/94	1820	05-MW-39	--	--	--	Could not locate under 2 ft of snow
4/16/94	845	05-MW-07	30.33	31.14	0.81	

Table 5-3
Phase III Hydrocarbon Recovery Summary (Winter 1994)

Well ID	05-MW-04	05-RW-2	05-W-2	05-MW-07	06-MW-04
Initial Measurements					
Original Product Level	27.77	27.93	28.42	30.33	25.09
Original Water Level	30.20	30.20	31.14	30.93	26.93
Original Product Thickness	2.43	2.27	2.72	0.60	1.84
Original Volume (gal.)	0.39	3.33	0.43	0.10	0.29
Recovery Results					
Time = 0 Thickness	0.15	0.41	0.92	0.00	0.11
1-Hour Thickness	0.66 (27.2%)	1.04 (45.8%)	2.50 (91.9%)	0.02 (3.3%)	0.97 (52.7%)
6-Hour Thickness	1.88 (77.4%)	1.68 (74.0%)	2.52 (92.6%)	0.07 (11.7%)	1.14 (62.0%)
12-Hour Thickness	2.23 (91.8%)	1.92 (84.6%)	2.4 (88.2%)	0.2 (33.3%)	Not measured
30-Hour Thickness	Not measured	2.00 (88.1%)	Not measured	Not measured	Not measured
48-Hour Thickness	Not measured	2.18 (96.0%)	Not measured	Not measured	Not measured
Estimated Formation Thickness	0.49	0.45	0.54	0.16	0.37
Skimming Results					
Well Skimmed?	No	Yes	No	No	No
Recovered Volume (gal.)	---	4.68 (141%)	---	---	---

Note: All results in feet unless noted otherwise"

Section 6
EVALUATION OF THE TREATABILITY STUDY

The TS was conducted to determine the effectiveness of soil vacuum extraction, air sparging, and steam injection on the treatment of hydrocarbon-contaminated soils and groundwater in the POL Tank Farm. The biotreatability of contaminants in the soils was also evaluated. The following discussion presents an analysis of the TS on the basis of the results presented in Sections 3 and 4.

6.1 Limitations Imposed by Site Conditions

Three features in the POL Tank Farm complicated the design, operation, and interpretation of results from the TS during the pilot-scale tests: 1) the fluctuating groundwater table, 2) the presence of free product, and 3) the lack of uniformity in contaminant levels throughout the site.

The water table at Galena fluctuates over 20 ft annually in response to changes in the Yukon River levels. The design for the Phase II pilot-scale system accounted for the fluctuating water table by including nested sparge points and vapor probes at two depths for the AS and steam injection systems and soil gas monitoring points, respectively. Figure 6-1 presents the water levels observed during the course of the Phase II test. The elevations of the well screens and injection points are presented for reference. The fluctuating groundwater table complicated the evaluation of the treatment system in that the volume of contaminated soil influenced by the SVE system increased throughout the study period because of the declining water table.

The second complicating feature was the presence of floating free-phase product. When the treatment system was designed, the thickness and behavior of free product in the POL Tank Farm had not been fully defined. Observations during the Phase II test indicated that initially no free product was present in the West Cell monitor wells but that large volumes accumulated as the water table dropped (see Figure 6-2). From baildown tests performed in April 1994, when the water table was low, the true free-product thickness is at least 0.6 ft over portions of the site. The presence of free product made an evaluation of the effectiveness of the remedial systems difficult because the floating product served as a constant source of volatile hydrocarbons. Although a mass balance has not been performed, it is likely that the mass of hydrocarbons removed by SVE during the pilot-scale test was only a small portion of the total contamination in the subsurface.

The third limitation was the variability of the hydrocarbon concentrations across the site. The Phase II test location was chosen on the basis of previous remedial investigations at the POL Tank Farm. Those investigations indicated high levels of BTEX, GRO, and DRO in soils and groundwater in this vicinity. During the installation of the pilot-scale remediation system components, it was obvious that the West Cell was significantly more contaminated than the East Cell. The average initial TPH concentrations in the soils at 9 to 10 ft bgl were 1140 ppm and 12 ppm for the West and East Cells, respectively. Since the contamination was different between the study areas, it is not possible to directly compare the monitoring results for the West and East treatment systems.

6.2 Feasibility of Winter Operation

One of the objectives of the TS was to determine if winter operation was feasible. In full-scale remediation, it is likely that a treatment system would have to operate at temperatures down to -50°F. For the Phase II pilot-scale systems, the process lines were heat traced and insulated to prevent condensation from freezing. The equipment enclosures were also insulated so that the heat of compression associated with the operation of the blowers was able to maintain the temperature in the enclosures well above freezing. The fact that the pilot-scale system had only minor operational problems caused by the cold temperatures indicates that year-round operation is possible.

6.3 Soil Vacuum Extraction System

The Phase I pilot-scale test provided evidence that SVE is a viable technology for treating petroleum-hydrocarbon-contaminated soils at the POL Tank Farm. Lessons were learned during Phase I concerning the optimum SVE design for the POL Tank Farm, such as the well construction details and the size of extraction

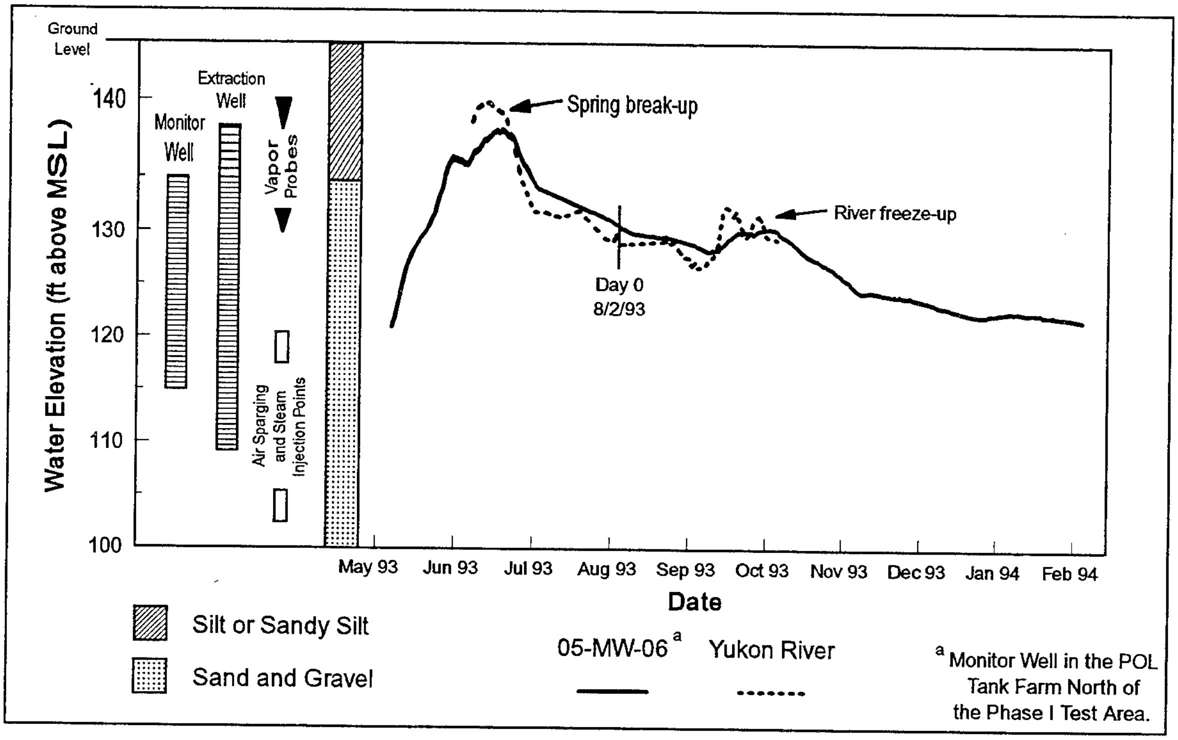


Figure 6-1. Annual Fluctuation of the Water Table at the POL Tank Farm. Approximate Elevations of the Wells and Injection Points in the Phase II Study Area Are Provided for Reference.

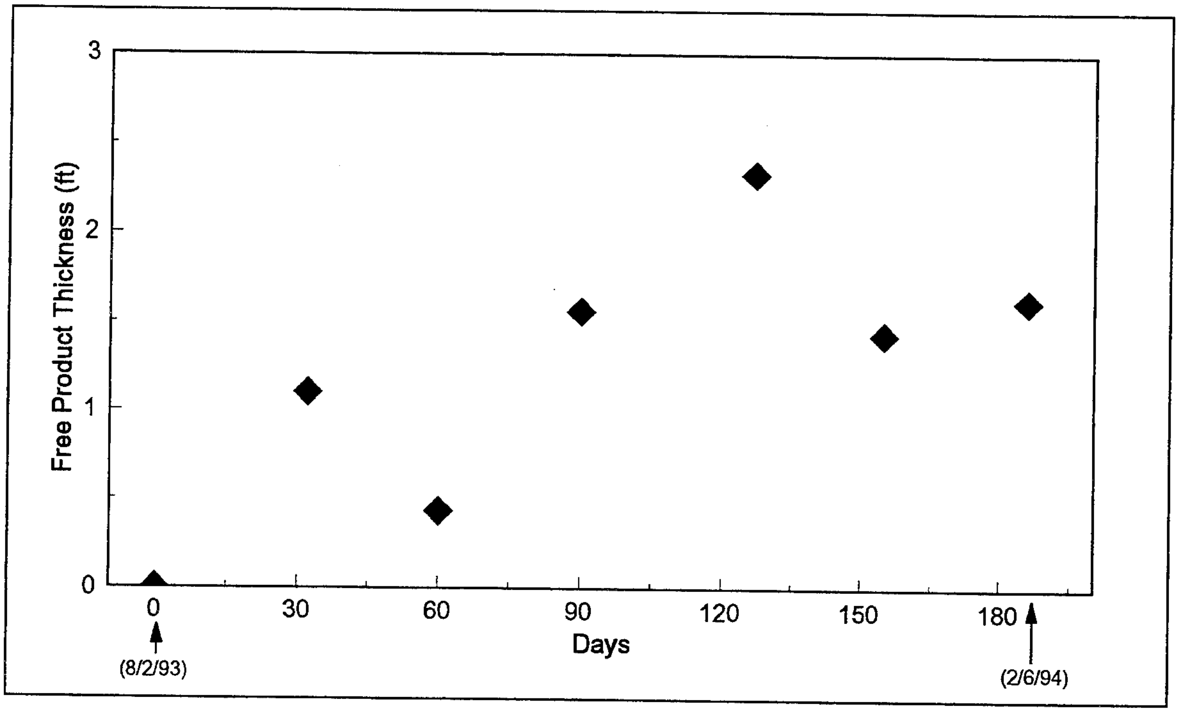


Figure 6-2. Average Free Product Thickness Observed in the West Cell Monitor Wells During the Phase II Test

well. This knowledge was applied to the Phase II design. The Phase II system, using the same SVE blower components as in the Phase I system, demonstrated marked improvement in performance over the Phase I system in terms of higher hydrocarbon removal rates. Flow rates for the Phase II system ranged between 120 and 150 scfm, and the effective radius of influence was estimated to be 100 to 200 ft. The Phase II system produced optimal performance while operating at full flow capacity. The results indicate that the soils could yield higher flow rates if a larger blower were used.

Both the East and West Cells proved to be very effective in removing hydrocarbons from the vadose-zone soils and groundwater. However, free-phase product present on the water table served to replenish the contamination in the vadose zone, particularly in the West Cell, so that the exhaust concentrations remained consistently high. The replenishment by the free product prevented any determination of the treatment time required to achieve total removal of hydrocarbon contaminants from the vadose-zone soils in the West Cell by the SVE system. Evidence that biological degradation was enhanced at the West Cell site using SVE was also collected.

Limited operational problems occurred during the duration of the TS. The East Cell SVE experienced a period when the system was automatically shutting itself off because the knockout tank reached capacity. This occurred during late September and early October when heavy rains caused the formation of a shallow perched water table around the extraction well. The knockout water collection system can be easily redesigned to prevent this from occurring in the future.

SVE has proved to be a very effective and reliable in situ treatment technology for petroleum-hydrocarbon-contaminated soils. The geology at Galena Airport is well suited for this type of remediation, as evidenced by the large flow rate and radius of influence achieved by the SVE systems. Performance data gathered during the TS indicate that SVE will be the presumptive remedy for the contaminated vadose zone at the POL Tank Farm.

6.4 Air Sparging System

The effectiveness of an IAS system is typically measured by evaluating dissolved contaminant concentrations and dissolved oxygen concentrations upgradient and downgradient of the injection wells, and by staged testing of a SVE system operated alone and in combination with IAS. The first two parameters were monitored in the pilot test; sequential testing of the SVE/AS systems was not conducted. However, a helium tracer test was also conducted at a single injection well to assess the zone of AS influence.

In the West Cell, the hydrocarbon constituents showed no discernable trend over the course of the pilot test. The dissolved contaminant concentrations remained constant because of the free product on the water table. As long as a free-product layer exists, new contaminants will dissolve to replace those removed by biodegradation or stripping. DO concentrations remained below 1 mg/L for the majority of the study period, indicating poor oxygen transfer from the sparged air to the groundwater. Similar results were obtained in the East Cell.

On the basis of the results of the study, air sparging, as currently implemented, does not appear to be particularly effective in removing dissolved-phase contaminants or increasing DO levels. The relatively constant dissolved contaminant concentrations over time and the similarity of the concentrations upgradient and downgradient of the air sparging wells indicate marginal hydrocarbon removal from the aqueous phase. One potential explanation for the observed ineffectiveness of the IAS system relates to the procedure for collecting groundwater samples. Samples were collected by extensively pumping the well with the pump inlet placed at the bottom of the well. The samples were representative of the entire screened interval rather than the top of the water column. The inability to collect point-source water samples from the upper portion of the saturated zone may have masked any differences between upgradient and downgradient water quality. Additionally, biological activity close to the injection points and interferences caused by floating hydrocarbons may have affected the field measurements for DO.

The most significant factor that affected the performance of the AS system was the small-diameter tubing (1/4 in.) used to deliver air from the wellhead to the sparge points. Frictional losses in the tubing caused a significant reduction in the maximum achievable flow rate from a design value of 4 scfm to a measured value of less than 1 scfm per well. The reduced flow rate thus led to a much smaller zone of influence for stripping and oxygen transfer. Recent literature on IAS has shown that higher flow rates (4 to 10 scfm per well) produce a larger and more uniformly distributed bubble pattern (Ji et al., 1993).

6.5 Steam Injection System

The effectiveness of the steam injection system was evaluated by measuring temperatures in the groundwater monitor wells and submerged thermocouples in the West Cell. Although the soil temperatures showed a significant increase over pretest levels, the temperature rise does not appear to be related to the steam injection system. The groundwater temperatures downgradient of the steam injection wells did not show any apparent trend except for an increase around Day 180, which is possibly related to biological activity (discussed in Section 5.6), since the steam injection system was shut off around Day 90 (three months before the Day-180 temperature measurements were taken).

On the basis of these findings, it appears that the steam injection system was not effective for its intended purpose: to generate a temperature rise of at least 10° C in the shallow groundwater. The following reasons may explain the observed ineffectiveness of the steam injection system:

- **Insufficient Steam Injection Rate**—The steam delivery system used small-diameter tubing from the wellhead to the injection screens (similar to the IAS system). This arrangement led to a large pressure drop in the well and low flow rates of injected steam. Thus, less heat was supplied to the subsurface than desired. Also, because water was supplied by a delivery truck rather than through a permanent water supply system, steam injection rates were limited by the storage capacity of the feedwater tank and the regularity of water deliveries.

- **Plugging of the Steam Delivery Tubes**—Some of the steam sparging points became clogged shortly after startup and resisted efforts to unplug them. Since these probes could no longer be used, the injected steam plume presumably was not as uniformly distributed as planned. Unfortunately, the two steam injection points that were plugged were those nearest the line of groundwater monitor wells used to measure groundwater temperatures.

- **Density Differences Caused by Heating**—Groundwater heated by steam would tend to rise to the top of the water column because of density differences between hot and cold water. During purging of the monitor wells prior to measuring groundwater temperatures, the cold and warm water regions may have been mixed so that the measured water temperatures were probably lower than what was actually present in the upper zone of the aquifer.

6.6 Hydrocarbon Removal Rate

The pilot-scale remediation systems removed subsurface hydrocarbons by both physical and biological processes. The SVE system physically removed the hydrocarbons from the soil by inducing a vacuum on the subsurface and pulling the soil gas and VOCs through an extraction well. Hydrocarbons were also removed from the contaminated zone by an aerobic biological oxidation process (i.e., the microorganisms used the hydrocarbon contaminants as a food source).

6.6.1 Physical Processes

The effectiveness of the treatment systems can be measured by the mass of hydrocarbons removed over time. The hydrocarbon mass removal by the SVE system was calculated from the flow rate and hydrocarbon concentration of the SVE exhaust gas and the estimated hours of operation. Appendix D.1 contains an example calculation for the mass removal rate. Figure 6-3 presents the cumulative mass of hydrocarbons removed by each unit during the Phase II test.

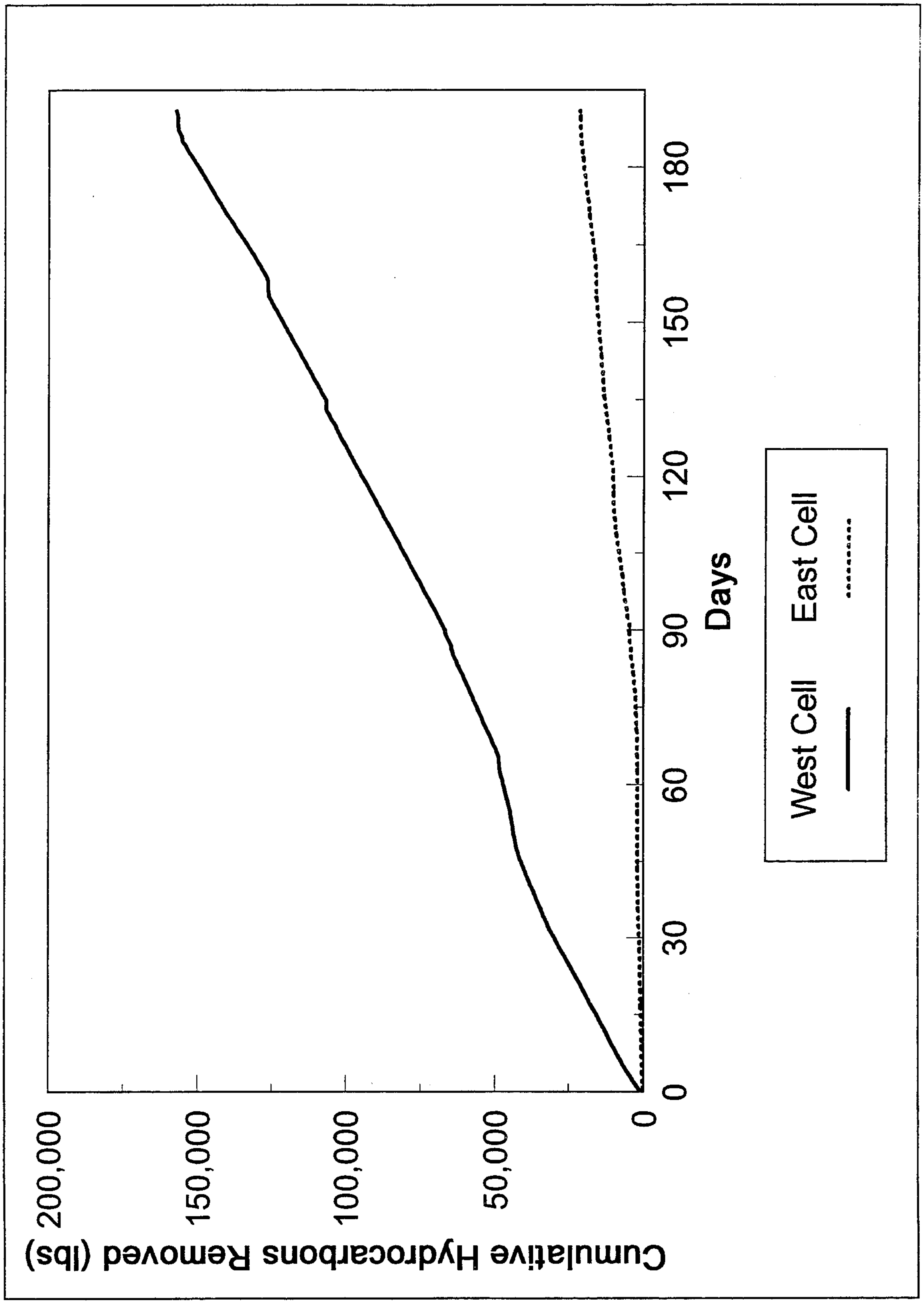


Figure 6-3. Cumulative Mass of Hydrocarbons Removed by the East and West SVE Systems

The mass of hydrocarbons removed from the West Cell was consistently greater than the mass removed from the East Cell. Nearly 160,000 lb (72,000 kg) and close to 21,500 lb (9800 kg) of hydrocarbons (as heptane) were removed from the West and East Cells, respectively, by physical processes. The average daily extraction rates for the West and East Cells were 380 and 50 kg/day, respectively.

The VOC concentration in the extracted soil gas was expected to decrease during the pilot-scale test on the basis of previous performance results for other SVE systems. Typically, sites treated by SVE have a finite mass of VOCs in soil pores within the radius of influence of the extraction well. Therefore, as the hydrocarbons are removed, the VOC concentration in the exhaust gas declines over time. There was no observed decrease in VOC removal rates for either SVE system.

West Cell

During the Phase II test, the concentration in the SVE exhaust gas from the West Cell averaged 20,000 ppmV TNMHC over the 192-day test. The consistently high concentrations observed were attributed to the fluctuating water table and the presence of free product in this portion of the site.

At the time of startup, the groundwater level was very high, situated in the silty layer. As the water table dropped into the more permeable sand and gravel layer, the zone of influence of the extraction well increased both vertically and horizontally. This allowed deeper portions of the hydrocarbon smear zone to be influenced by the vacuum on the extraction well.

Secondly, as the water table dropped, residual free-phase hydrocarbons trapped in the soil pores drained downward causing free-phase product to pool in the monitor wells and surrounding strata. The large apparent accumulation of free product in the West Cell (up to 4.0 ft in monitor well W-2) acted as a continual source of VOCs during the test. Therefore, as the hydrocarbons were removed from the vadose zone, the contamination was replenished by the volatilization of constituents from the free product floating on the water table. This could explain why the TPH concentrations in the West Cell soils did not decline significantly during the test, even though nearly 160,000 lb of hydrocarbons was removed.

East Cell

The East Cell showed much lower rates of hydrocarbon removal because of the lower levels of contamination in this portion of the study area. The hydrocarbon concentration in the SVE exhaust gas decreased initially and then rose after Day 60. From Day 15 through Day 60, the East SVE operated inconsistently because of the high rate of water collection in the knockout tank and intended system outages. During this time, the SVE vacuum was manually decreased to reduce the amount of water collected by the system; the vacuum was decreased by bleeding in ambient air, which caused the exhaust gas to be diluted; this resulted in decreased hydrocarbon concentrations in the exhaust gas.

As the water table dropped into the more permeable sand and gravel zone, the VOC concentrations increased and averaged 2900 ppmV TNMHC during the last three months of the test. Like the West Cell, the exhaust gas concentrations in the East Cell did not show a decreasing trend over time.

The hydrocarbon concentrations in the East Cell soils at the end of the study period were below the method detection limit, having decreased from a maximum of 43 ppm to below 1 ppm. The decrease in soil concentrations was attributed to removal by the SVE system. Since there was no free product observed over most of the East Cell, the vadose zone was apparently not being replenished with hydrocarbons. Free product was present initially in the monitor well south of the East Cell, W-8, but the thickness decreased throughout the test until it disappeared entirely by Day 150. It is likely that some of the contaminants removed by the East SVE were pulled from the free product thought to be present on the western and southern portions of the East Cell.

6.6.2 Biological Processes

The biodegradation of hydrocarbons at the POL Tank Farm was also evaluated during the Phase I bench-scale and Phase II pilot-scale tests. When microorganisms degrade organic material aerobically, oxygen is consumed and carbon dioxide is produced. This process is also exothermic, meaning that heat is released during the biochemical breakdown of organic material. Since microorganisms use hydrocarbon contaminants as their food source, if this contamination is not present, the organisms will not thrive.

Several types of data from the Phase II pilot test suggest that significant biodegradation of hydrocarbons was occurring in the West Cell. These data types include in situ respiration rates, the soil gas composition data, and the soil temperature measurements. Measured biodegradation rates, carbon dioxide concentrations, and soil temperatures were highest, and the oxygen concentrations were lowest in the area of highest TPH contamination in the western portion of West Cell. The minimally contaminated areas did not show these trends. Figure 6-4 presents a diagram showing the contours of these biological indicators in the study area. Each factor is discussed below in more detail.

Biodegradation Rate

Table 6-1 summarizes the biodegradation rates for vadose-zone soils calculated using the most reliable data from the Phase I bench-scale and Phase II pilot-scale tests. The biodegradation rate was calculated from the following data: 1) oxygen utilization rates from the Phase I bench-scale test and the Phase II in situ respiration tests, and 2) TPH removal in the soils during the bench-scale test.

Table 6-1
Hydrocarbon Biodegradation Rates (mg/kg/day) Determined During the Treatability Study

Bench Test Rate (O_2 Uptake[a])	Bench Test Rate (TPH Removal[b])	Pilot Test Rate (O_2 Uptake[c])	
1.2	8.0	3.2	West Cell
		0.2	East Cell

Notes: [a]Estimated biodegradation rate of model hydrocarbon (heptane) is based on reaction stoichiometry and the rate of oxygen utilization for the unamended 21% O_2 bench-scale treatment condition. [b]Degradation rates calculated using initial and final TPH concentrations in soil for the unamended 21% O_2 bench-scale treatment condition. [c]Estimated biodegradation rate of model hydrocarbon (heptane) based on reaction stoichiometry and rate of oxygen utilization during the Phase II field respirometry tests.

The estimated biodegradation rates for the bench and pilot tests agree within an order of magnitude. The rates calculated from the Phase II respirometry tests are generally thought to provide the most reasonable estimate, since these results represent in situ field measurements for an actual remediation system. Therefore, the best estimate for the biodegradation rate in the West Cell (within the contaminated zone) is 3.2 mg/kg/day. The best estimate for the biodegradation rate in the East Cell is 0.2 mg/kg/day.

Soil Gas Measurements

The soil gas measurements during the Phase II test also indicate significant biological activity in the West Cell. The steady-state concentrations of oxygen and carbon dioxide in the most active areas of the West Cell were 14% and 6%, respectively. These levels are significantly different from ambient conditions (21% and 0.03%). Since ambient air is pulled through the subsurface by the SVE system, areas that do not show significant biological activity would have a soil gas composition that is near ambient conditions. Ambient conditions were observed in the less-contaminated portions of the West Cell and throughout the East Cell.

Soil Temperatures

Soil temperatures in portions of the West Cell increased substantially during the six-month test period and were much higher than ambient soil temperatures. The temperature distribution in the West Cell soils is shown in Figure 6-4. Soil gas temperatures in V-1 through V-4 increased an average of approximately 18°C between Day 60 and Day 150. The soils remained thawed at the surface whereas ambient soils in other parts of the study area froze to a depth of several feet. The elevated soil temperatures could not be directly correlated with either the operation of the steam injection system or the presence of steam heat lines contained in the utilidor running along the southern margin of the study area. Additional temperature measurements were taken outside the original study area, but the location of additional measurement points was limited by buried utility lines, roadways, and soil and rubble heaps. On the basis of these measurements, the most likely heat source for the West Cell appears to be biological activity associated with the degradation of hydrocarbons in the subsurface. It is hypothesized that biological activity was triggered by the introduction of oxygen to the subsurface by the SVE system.

Heat balance calculations were used to evaluate whether the temperature regime observed in the Well Cell could be attributed to heat from the biological metabolism of the hydrocarbons present in

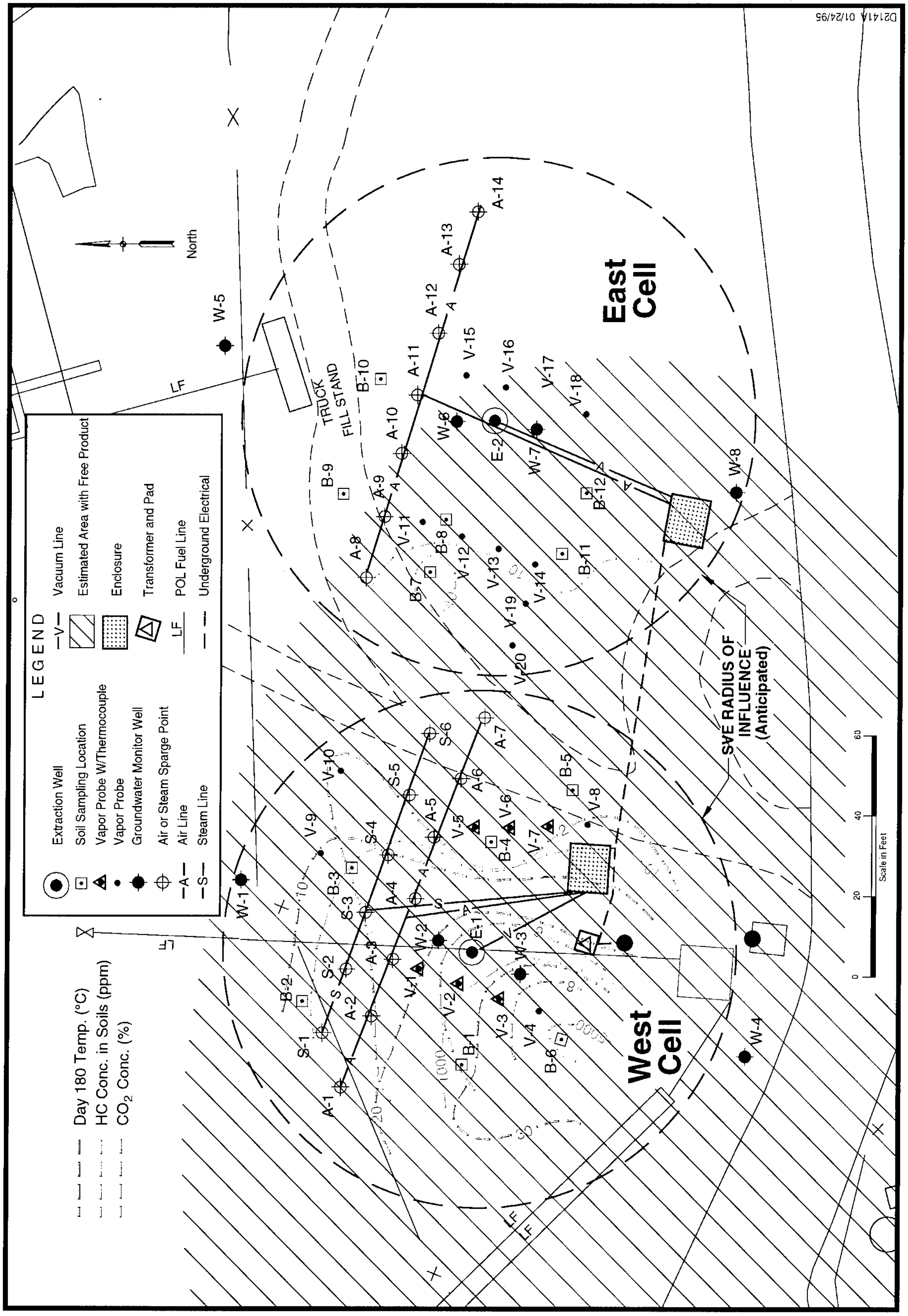


Figure 6-4. Contour Map of Biological Indicators and Hydrocarbon Concentrations in the Study Area

the soil. On the basis of the biodegradation rates estimated in the West Cell, the maximum expected temperature rise in the West Cell is 34°C over the 180-day test (see calculation in Appendix D.2). This temperature rise is idealized, since heat losses to the surrounding soil were not considered. Other heat loss calculations, which do not take into account any insulation effects for the snow cover in the study area, show that the heat generated by the metabolism of heptane is slightly more than one fifth of the heat required to maintain the temperature regimes observed at Day 150. However, the vapor probe locations where oxygen uptake rates were measured were about 15°C cooler than the highest temperatures measured for the soils. Since microbial activity rises exponentially with temperature, the estimated biodegradation rates may be significantly greater in the warmer zone. The variability in soil temperatures and biodegradation rates could fulfill the heat requirements needed to generate the observed temperature profile.

In summary, since the contamination and temperature distribution patterns are not well understood inside the study area and even less so outside the study area (especially west of the West Cell), it is difficult to confirm beyond doubt that biological activity is the cause of the temperature rise seen during the Phase II test. However, since the area of maximum soil temperatures was situated west of the vapor probes used to estimate the biodegradation rates, it is possible that the degradation rates in other areas of the West Cell may be higher than those estimated during the pilot test. On the basis of the field results and the absence of any other heat source, the most reasonable cause for the temperature rise in the West Cell is microbial.

Hydrocarbon Removal

The mass of hydrocarbons removed from the West Cell by biological processes was estimated at 23,500 lb during the 180-day test. This calculation is provided in Appendix D.3. Minimal biodegradation occurred in the East Cell, where approximately 590 lb were estimated.

6.6.3 Comparison of Removals

Table 6-2 summarizes the total mass of hydrocarbons (as heptane) removed by physical and biological processes during the Phase II pilot-scale test. Biodegradation accounted for approximately 13% and 3% of the hydrocarbon removal in the West and East Cells, respectively.

Table 6-2
Summary of Hydrocarbons Removed During the Phase II Pilot-Scale Test

Study Area	Mass Removal (lbs)	
	Physical Process	Biological Process
West Cell	160,000	23,500
East Cell	21,500	590

6.7 LNAPL Recovery System

Free-product surveys, baildown tests, and skimming tests were conducted during three separate occasions as part of the TS. The first two phases of this test program were conducted during the summer and fall 1993 during the normal high-water-table portion of the annual hydrological cycle of the Yukon River. Test results from those periods indicated that a thin, discontinuous, and largely irrecoverable LNAPL layer existed below parts of the POL site. Free-product measurements taken during the course of the Phase II SVE test indicated that LNAPL accumulates on the groundwater table during the winter (refer to Figures 4-9 and 4-17). A third phase of LNAPL recovery testing conducted in April 1994 indicated that a substantially different set of hydrologic conditions exists during the winter low-water table period. Estimated LNAPL formation thicknesses measured at that time ranged up to 0.6 ft in the POL area. The testing results also indicate that product skimming during the winter should be practical.

The free-product recovery system should be designed for winter operation, since the best recovery rates have been observed during the low-water table period. Since free-product recovery and SVE are complementary remedial actions, they could be implemented concurrently for the remediation of the LNAPL layer and vadose-zone soils.

Although problems related to cold-weather skimming operations were experienced, it is our opinion that these are not insurmountable problems that would rule out further attempts to recover LNAPL using the SOS system or a similar skimmer system design. The freezing of the discharge hose was not surprising, considering that temperatures were between 0° and 15°F at the time of testing. This problem could be corrected by insulating (and possibly heat tracing) all air hoses, product discharge hoses, and recovery well risers.

6.8 Conclusions

The following list summarizes the most important results and interpretations from the TS at Galena Airport:

- SVE is a viable technology for treating petroleum-contaminated soils at the POL Tank Farm. Over 180,000 lb of VOCs were removed from twin SVE systems during a 6-month period of operation. The site stratigraphy is particularly conducive for this technology, as evidenced by the high gas flow rates and large zone of influence.

- The design of an in situ system must take into consideration three key site features: 1) a water table that annually fluctuates over a 20-ft range, 2) the seasonally varying thickness of the free-product layer, and 3) the horizontal and vertical variability of soil contaminant patterns.

- Observations during the Phase II pilot-scale test suggest that VOC removal rates would be higher if a larger blower was used for the SVE system.

- Extraction of VOCs from the free product floating on the groundwater prevented any determination of the treatment time required to remediate the soils using SVE. No significant decline in VOC removal rates was observed over the operational period.

- The pilot-scale in situ air sparging and steam injection systems demonstrated marginal benefits toward total site remediation. However, the evaluation of the pilot-scale systems was limited by inadequate air and steam delivery systems, boiler operating problems related to poor feedwater quality, and the inability of the monitoring system to detect spatial changes in dissolved oxygen concentrations and temperatures of groundwater.

- LNAPL formation thicknesses up to 0.6 ft were observed during April 1994. Also, a skimmer system recovered more than four times the volume of LNAPL in a recovery well before operation problems caused the skimming activity to stop. The results indicate that product removal during the winter months should be feasible.

- Several lines of evidence indicate that significant biodegradation of hydrocarbons was occurring, especially in the West Cell. These include oxygen uptake rates, soil temperature contours, oxygen and carbon dioxide levels in the soil gas, and correlations of the above with hydrocarbon distribution patterns. The average hydrocarbon degrada-tion rate was estimated to around 3 mg/kg/day in this area, although soil temperature patterns suggest that rates could be significantly higher.

- The quantity of hydrocarbons removed through biological processes is estimated at approximately 22,000 lb. This amounts to approximately 13% and 3% of the total mass of hydrocarbons removed in the West and East Cells, respectively.

- Year-round operation of an in situ remediation system at Galena Airport is feasible.

Section 7
RECOMMENDATIONS FOR TECHNOLOGY IMPLEMENTATION

At the Galena Airport POL Tank Farm site, leaking pipes, tanks, and spills over a 30-year operating period served as a source of fuels that have migrated downward to the water table. Site investigations and treatability studies conducted under the USAF IRP now provide an understanding of the contaminant migration behavior. Figure 7-1 presents a conceptualized model of the subsurface conditions at the POL Tank Farm. The contamination that began initially around the saddle tanks has now extended beneath the airport tarmac. Both free phase and dissolved phase have migrated. During the summer months, the water table is high and free product is spread across and entrained in the silty upper strata by capillary forces. During the winter months, when the groundwater table drops, gravitational forces cause the product to drain downward and pool on the groundwater. The free-product layer provides a continuous source of contaminants to the soil and groundwater and therefore hinders attempts to remediate the affected zones in a timely manner.

This section discusses recommendations for selecting and implementing a successful remediation program at the POL Tank Farm. It is recommended that the remediation program include the following components:

- Free-product recovery;
- Remediation of residual contamination in the soils using SVE (this could be implemented concurrently with free-product recovery); and
- Following source removal, remediation of dissolved-phase contamination may be considered (the decision whether to remediate groundwater further should be based on a risk assessment).

7.1 Free-Product Recovery

Free-product surveys, baildown tests, and skimming tests were conducted during the fall of 1992 and summer of 1993 on groundwater monitor wells in the POL Tank Farm area (refer to the *Draft Remedial Investigation Report*, USAF, 1993e). The results of those activities conducted during a high-water table period indicated that a thin, discontinuous, and largely irrecoverable LNAPL layer existed through parts of the POL Tank Farm site. Recent hydrocarbon recovery tests conducted in April 1994 indicate that a substantially different set of hydrologic conditions exist during the winter low-water table period. The test results indicate that product skimming during the winter should be practical (USAF, 1994).

Since little was known of the horizontal extent of free product or its seasonal movements in early 1992 when the TS was begun, the pilot-scale tests focused primarily on the remediation of vadose-zone contaminants and to a lesser degree on the remediation of groundwater contaminants. Although the results of this TS and other studies have shown that SVE is capable of reducing the volume of free-phase product, the estimated thickness of free product in the POL Tank Farm warrants a direct remedial action. It is strongly recommended that an LNAPL recovery (skimming) system be implemented concurrently with SVE during the full-scale remediation of the POL Tank Farm site.

The free-product recovery system should be designed for winter operation, since the best recovery rates have been observed during the low-water table period. In terms of the type of product recovery system to be considered, we recommend that a multiwell recovery system be installed and operated. Figure 7-2 shows a preliminary design for the recovery well placement. The system can use several existing monitor and recovery wells that have been shown to produce extractable volumes of floating product.

7.2 Residuals Treatment

The TS results demonstrate that residual hydrocarbon contamination, which has smeared across the entire vertical range of groundwater fluctuations, can be effectively remediated with SVE once the LNAPL is sufficiently depleted. In addition to the physical removal of VOCs, the TS results also indicate

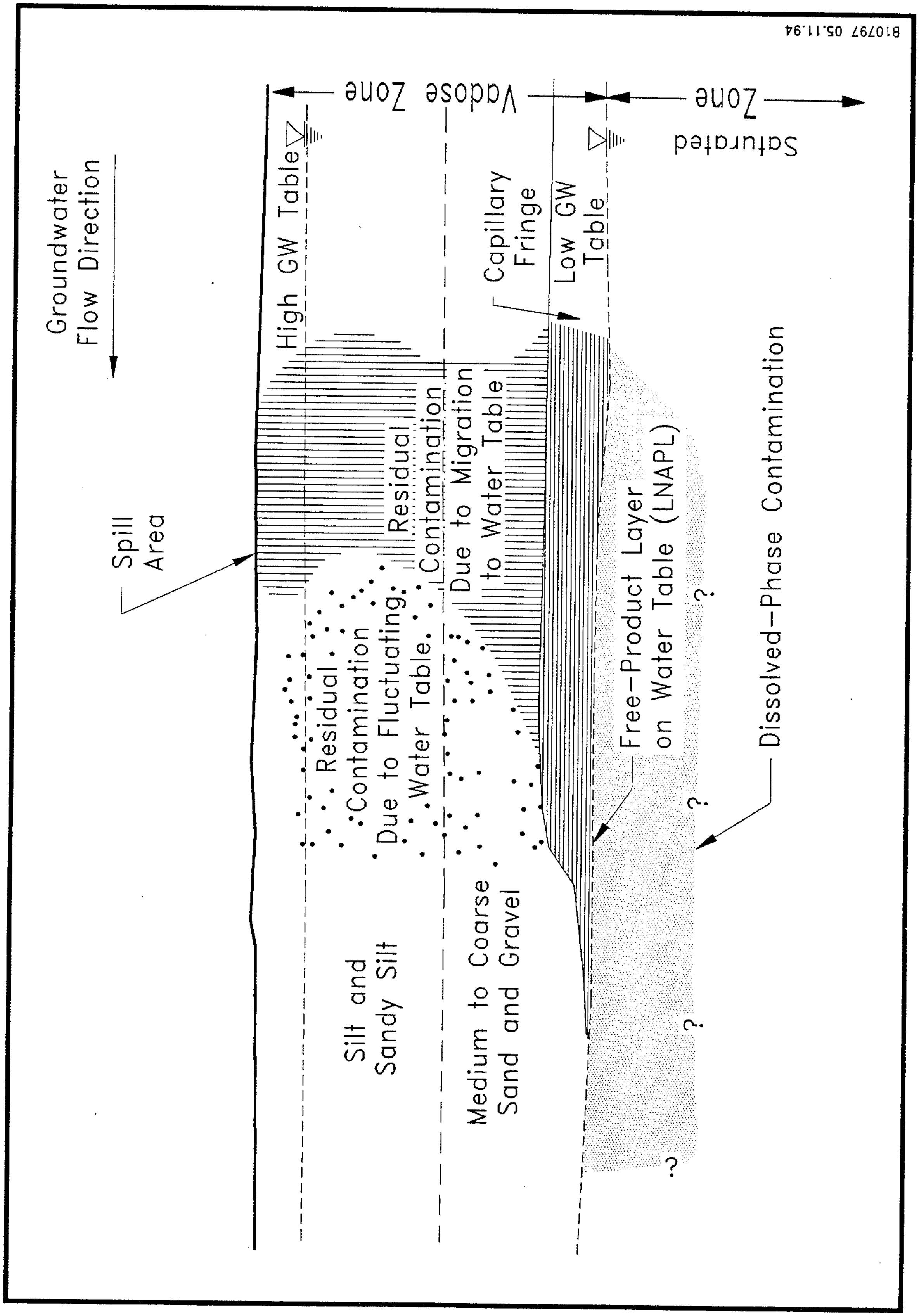


Figure 7-1. Conceptual Hydrocarbon Migration Pattern at Galena Airport

that significant biodegradation of the residual contaminants in the vadose zone can be achieved through SVE treatment.

SVE is therefore the obvious choice for residuals treatment and is currently the presumptive remedy for soil contamination at the POL Tank Farm. The stratigraphy of the site is particularly conducive for remediation using this technology, as evidenced by the high gas flow rate and large zone of influence of the SVE system. However, SVE is most effective for constituents present in the vadose zone that have high vapor pressures (e.g., BTEX, short-chain aliphatics, other aromatics, etc.); removal of the less-volatile components is less efficient. Also, hydrocarbon residuals present in the continually saturated zone will not be efficiently remediated by SVE alone.

In situ bioremediation of residual components was enhanced by the SVE system. Although the TS results did not show that either air sparging or heat addition was particularly effective in this area, these are still considered potentially viable technologies. Heat could further enhance biodegradation and have the added effect of increasing volatilization. Additionally, other studies (Johnson et al., 1993) have shown that air sparging can be effective for treating residuals below the groundwater table.

The TS results show that the presence of LNAPL hinders remediation efforts using SVE because the free-phase and dissolved-phase constituents replenish soil contaminant levels when the water table rises each spring. It is apparent that free-product skimming is required along with residuals treatment.

7.3 Dissolved-Phase Treatment

Once free product and residual hydrocarbon contamination have been addressed, the remediation of the dissolved-phase groundwater contamination can be considered. It is recommended that dissolved-phase treatment be initiated only after significant source removal (free product and vadose-zone residual contamination) has occurred.

Pump and treat technologies, such as air stripping, are widely accepted for the treatment of groundwater contaminated with petroleum hydrocarbons. However, because of the remoteness of Galena Airport, it is desirable that the chosen technology be as simple as possible and generate minimal wastes requiring treatment or disposal. For these reasons, in situ techniques are favored. Alternatives include air sparging, vacuum-vaporizing wells, groundwater containment, heat treatment, and natural bioattenuation. Air sparging and vacuum-vaporizing technologies are reportedly both effective in stripping VOCs from groundwater, but there are few well-documented studies to confirm the claims. It has also been postulated that once source removal is complete, the dissolved-phase concentrations might be reduced sufficiently to allow natural bioattenuation to complete the treatment process.

7.4 Design Considerations

The TS findings have answered most of the questions concerning selection and implementation of remedial actions at Galena Airport. Remedial design can proceed at the POL Tank Farm site on the basis of the information collected during the TS and remedial investigation. However, certain design parameters have not been fully defined, and the benefit-to-cost ratio of not obtaining this information should be considered.

The full extent of the free-product layer and the vertical extent of the dissolved-phase groundwater plume have not been fully defined. Estimates of these distributions have been made and could be used for remedial design purposes. However, some risk exists that the implemented system might not fully encompass the contaminated zone so that the system would have to be expanded later. Also, the potential recovery rate and radius of influence of the recovery wells are unknown. Field tests may therefore be warranted to avoid costly design adjustments during remedial implementation.

Additionally, there is the need to identify which type of vapor control system will be operated in conjunction with SVE. Although the Alaska Department of Environmental Conservation has allowed VOCs from the pilot tests to be vented to the atmosphere, it is probable that VOC emission controls would be required for a full-scale SVE system. On the basis of the high concentrations of VOCs observed during the Phase II pilot-scale test, the best-suited control technologies include thermal incineration and condensation. Carbon adsorption proved to be cost prohibitive during the study. The final choice will depend on the target removal efficiency, available disposal options for petroleum condensate, and cost.

A third concern is the fact that the TS was unable to make a definitive conclusion as to the benefits of using air sparging or steam injection for groundwater remediation. Deficiencies in pilot-scale systems and monitoring program resulted in relatively poor performance of those systems; therefore, the expected benefits of AS and steam injection were not fully observed. However, these deficiencies should not rule out air or steam sparging as potential technologies to be considered for remediating dissolved-phase contaminants at the POL site or other Galena Airport sites. The Air Force and other organizations are currently supporting evaluations of sparging technologies and the results of those investigations should be relied on to make decisions concerning whether these technologies are appropriate for Galena Airport.

7.5 Summary

Multiple technologies will be needed to effectively remediate the contamination at the Galena POL Tank Farm. The IRP USAF TS has shown that product recovery is a necessary and practical first step and that SVE is an effective treatment technology for vadose-zone soils contaminated with petroleum hydrocarbons. The product recovery and SVE systems could be run concurrently as a combined source removal effort. Once free product is sufficiently depleted, the time requirements for remediating the residual hydrocarbons in the vadose zone and the dissolved contaminants in the saturated zone can be more adequately addressed.

A conceptual design for a full-scale remediation system for the POL area is illustrated in Figure 7-2. Although conceptual, this design focuses on the primary remediation concerns at the POL Tank Farm and adjacent areas and could be practically installed and operated at this site. The radius of influence of the SVE well is 130 ft, based on TS findings. The radius of influence of the free-product recovery wells is largely unknown but estimated to be at 40 ft.

Future design work on a full-scale remediation system for the POL Tank Farm site will determine the optimum location of each remedial component and the necessary sequence of activities to complete the remediation. The ongoing feasibility study will address the potential groundwater treatment technologies applicable to Galena Airport and the POL Tank Farm.

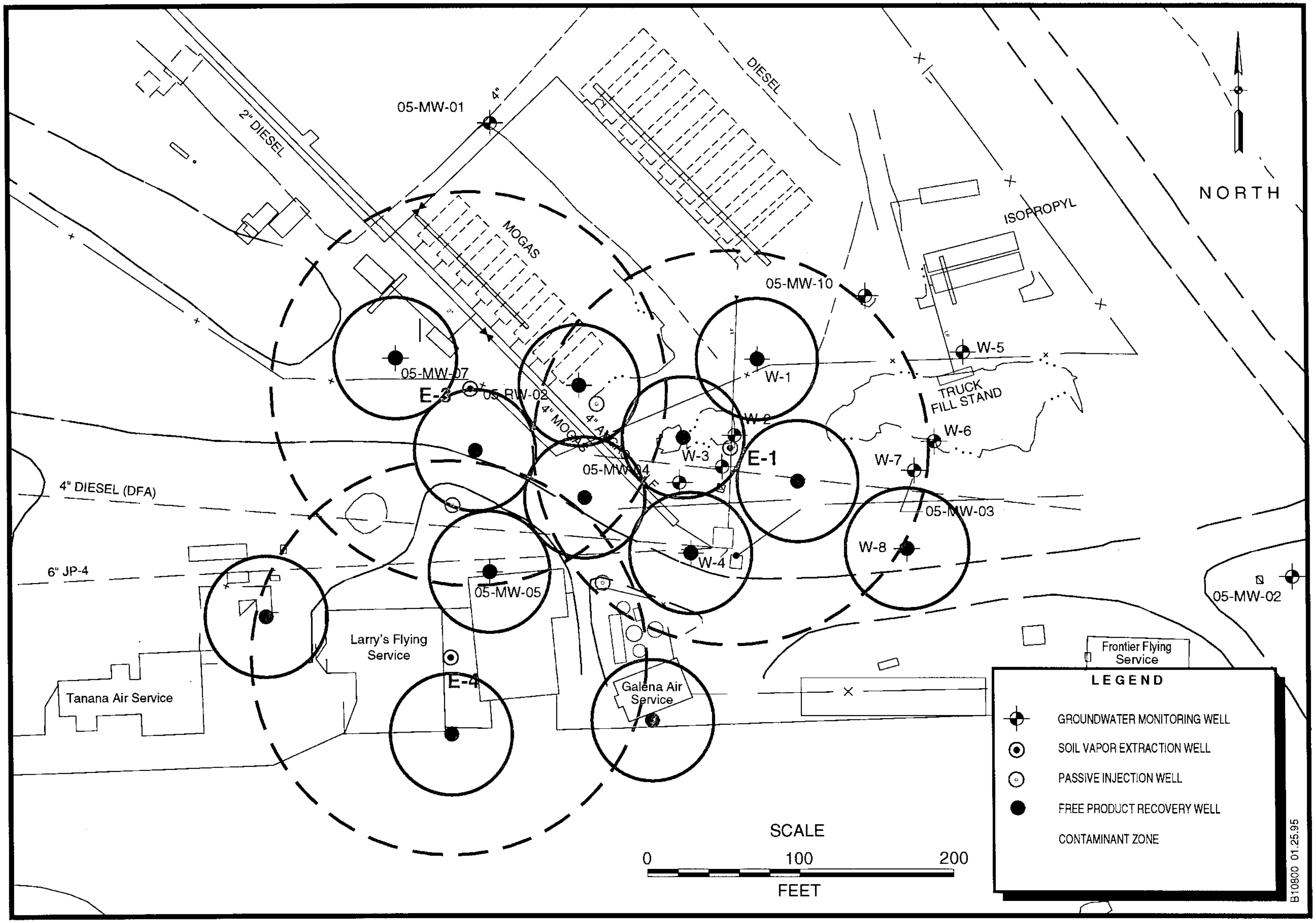


Figure 7-2. Conceptual Design of a Full-Scale Remediation System at the POL Tank Farm

Section 8
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APPENDIX A

Phase I Pilot-Scale SVE Test

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APPENDIX A.1

Well Construction Diagrams

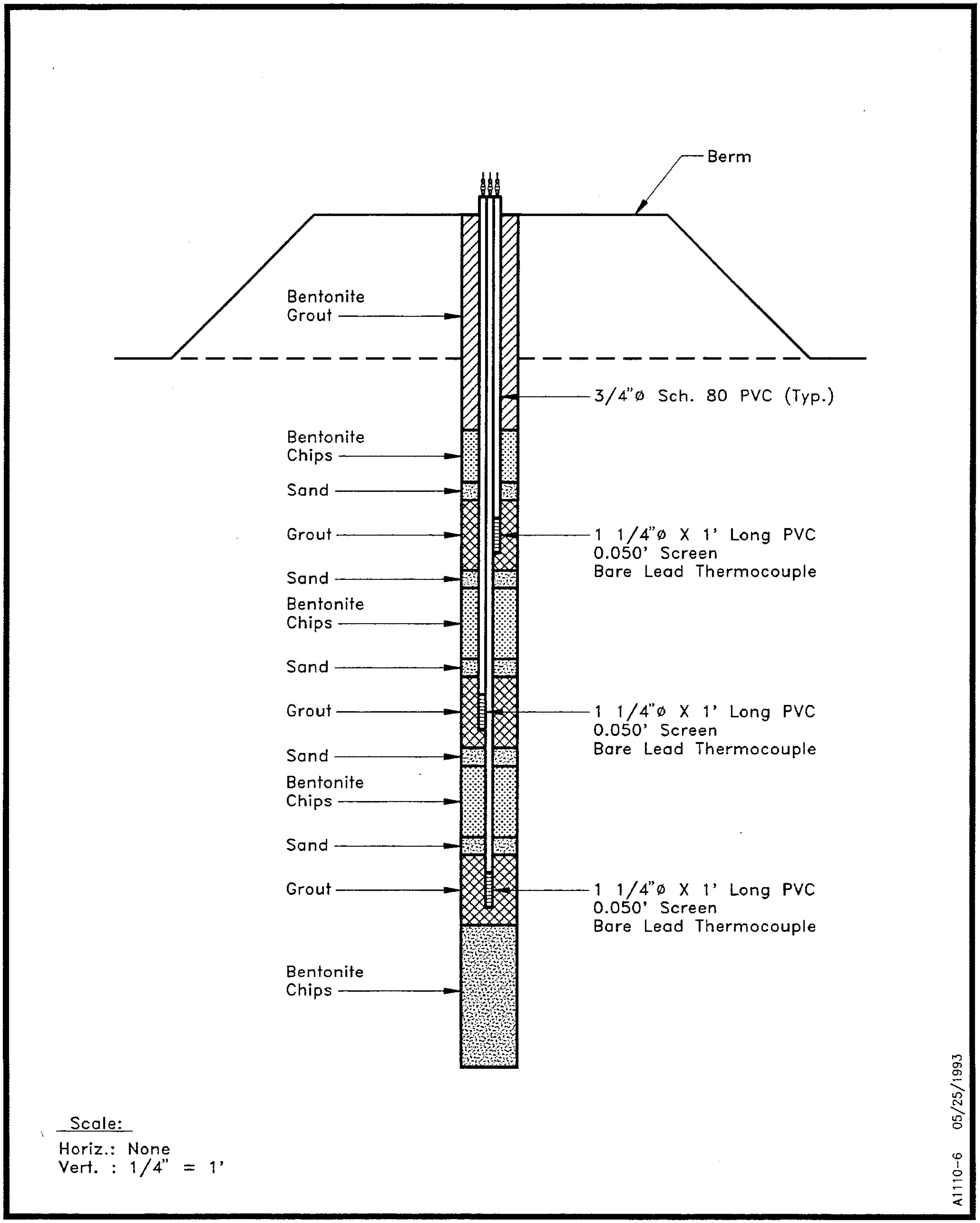


Figure A-1. Construction Details for the Vapor Probe Wells

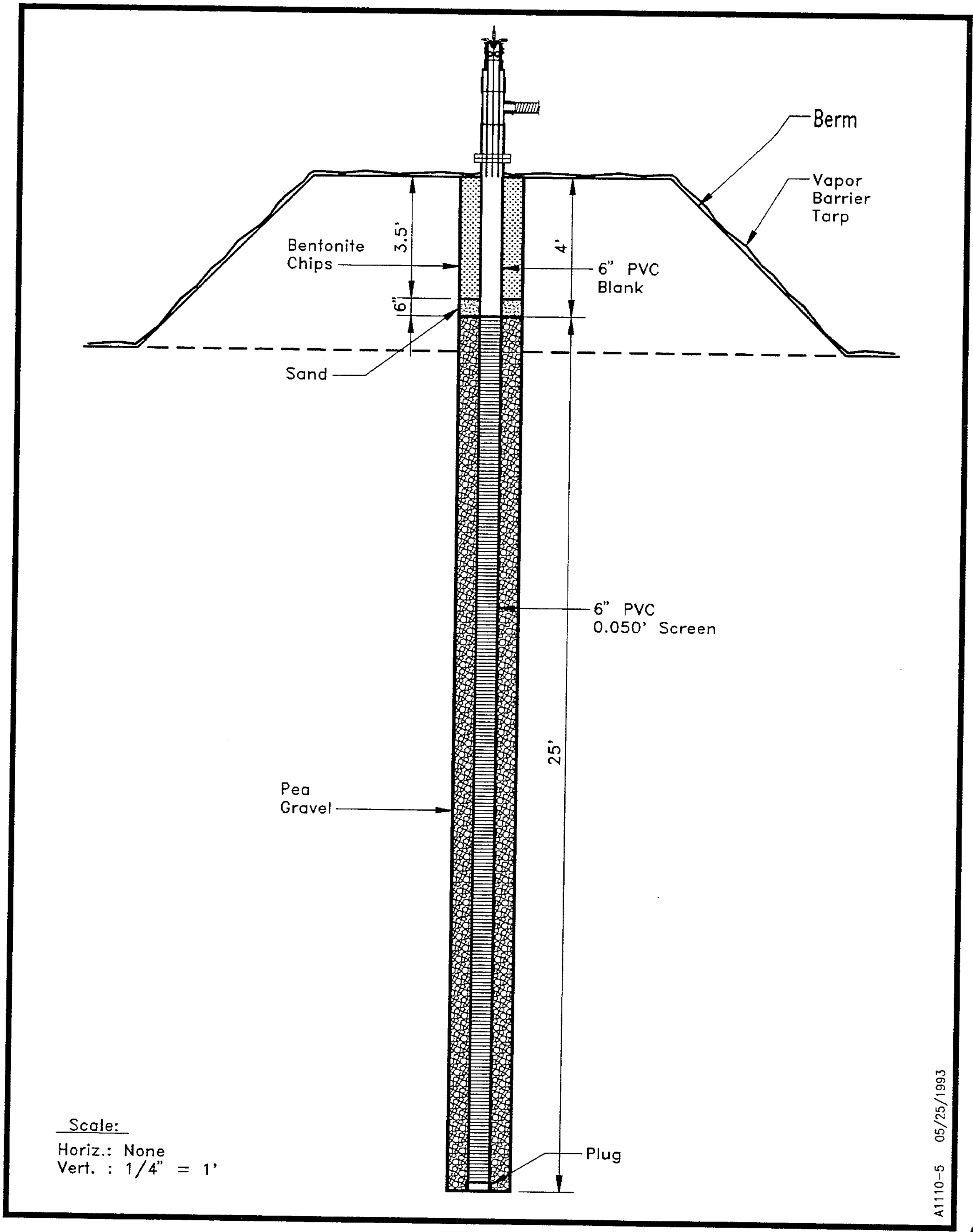


Figure A-2. Construction Details for the Soil Vacuum Extraction Well

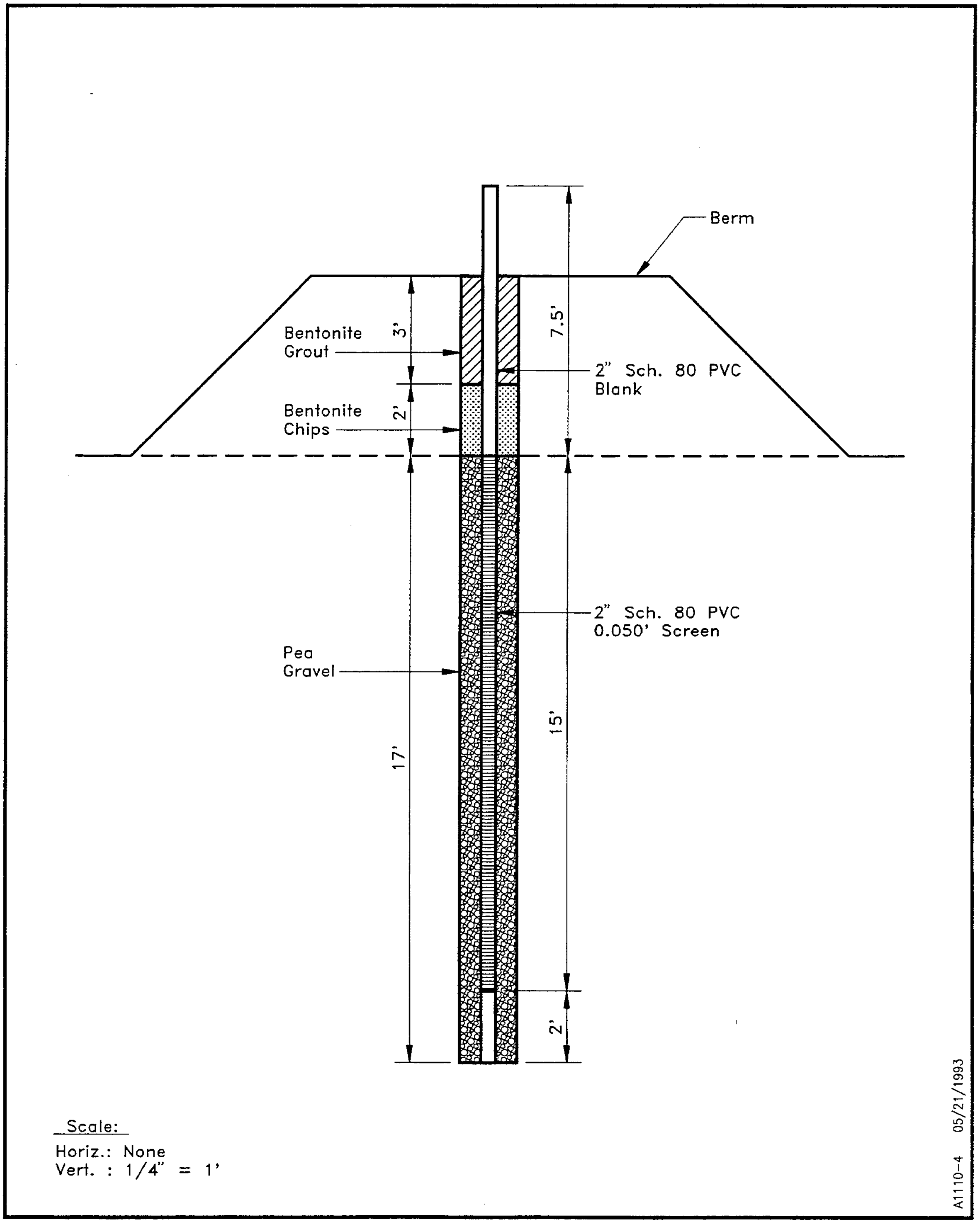


Figure A-3. Construction Details for the Passive Inlet Wells

APPENDIX A.2

Analytical Results

Table A-1

Analytical Data for Soil Gas Samples
(Values are Parts Per Million Volume)

Location	Type	Total VPH	Benzene	Ethyl benzene	Toluene	Xylenes
Sampling Event G1 -- 30 Jul 92						
V1-05	N	14600	495	30.5	567	115.9
V2-05	N	4790	123	31.5	165	116.2
V3-05	N	38900	1200	51.1	1080	189.2
V4-05	N	596	2.76	3.11	1.53	5.8
V5-05	N	1130	36.5	3.31	4.32	6.43
E1	N	1910	73	27.8	134	124.8
E1	FD	1210	43.5	22.6	91	93.9
Sampling Event G2 -- 04 Aug 92						
V1-05	N	416	13.1	36.4	66.7	122.9
V2-05	N	8100	190	153	595	791
V3-05	N	31900	895	53.4	837	216
E1	N	4860	78.5	222	425	1177
Sampling Event G3 -- 21 Aug 92						
V1-05	N	11300	229	69.6	257	260.5
V1-10	N	18300	713	113	1320	436.5
V2-05	N	6370	150	33.6	200	125.6
V2-10	N	604	14.2	1.84	13	8.31
V3-05	N	31200	598	47.8	664	181.6
V3-10	N	8900	189	21.1	182	82.4
V4-05	N	400	7.59	0.85	8.16	3.06
V4-10	N	963	3.02	1.39	4.82	2.91
V5-05	N	1030	23.6	15.2	50.5	48.2
V5-10	N	7150	133	22	147	73
E1	N	298	10.8	1.19	6.23	3.2
E1	FD	456	17.9	1.17	9.54	3.53
EX	N	748	43.6	1.27	1.58	3.14
Sampling Event G4 -- 05 Sep 92						
V1-05	N	1400				
V1-10	N	6150				
V2-05	N	1870				
V2-10	N	1370				
V3-05	N	3800				
V4-05	N	45.6				
V4-10	N	940				

Table A-1
(Continued)

Location	Type	Total VPH	Benzene	Ethyl benzene	Toluene	Xylenes
V5-05	N	30.4				
V5-10	N	41.2				
V5-10	FD	31				
E1	N	2460	81.8	5.57	71.9	26.87
E1	FD	2650	91.5	3.22	59	16.68
Sampling Event G5 -- 29 Sep 92						
V1-05	N	117	0.27	0.85	0.94	1.75
V1-10	N	2170	99.6	9.17	116	37.62
V1-15	N	18700	655	103	966	321
V2-05	N	11400	257	4.64	344	48.59
V2-10	N	745	23	3.33	12.8	9.45
V2-15	N	56700	1780	139	1830	358.3
V3-05	N	18300	308	76.6	523	315.6
V3-05	FD	16500	311	35.1	233	132.8
V3-10	N	7150	98.4	53.9	305	183.4
V3-15	N	25900	1000	50.4	536	90.2
V4-10	N	97	0.37	0.73	1.51	1.23
V4-15	N	91.5	0.5	0.88	1.94	2.13
V5-05	N	1560	32.9	2.94	51.8	12.35
V5-10	N	106	1.08	4.65	7.84	6.19
V5-10	FD	47.9	0.82	0.79	2.09	1.17
V5-15	N	705	27.7	1.25	9.46	4.4
E1	N	146	5.44	2.37	7.08	2.91

NOTES: Type N = normal. Type FD = field duplicate.

Table A-2
Oxygen and Carbon Dioxide Concentrations and Temperatures Measured in Vapor Wells

Vapor Probe	O_2 (%)	CO_2 (%)	Temperature (°C)
Event 1 - 30 Jul 92			
V1 - 5 ft.	0.5	12.5	0.8
V2 - 5 ft.	6.5	3.5	2.0
V3 - 5 ft.	1.5	11.0	1.6
V4 - 5 ft.	3.0	15.0	1.1
V5 - 5 ft.	5.0	5.5	0.5
Event 2 - 4 Aug 92			
V1 - 5 ft.	19.0	0.0	0.0
V2 - 5 ft.	12.5	3.1	2.0
V3 - 5 ft.	5.5	10.5	1.2
V4 - 5 ft.	1.5	8.5	0.4
V5 - 5 ft.	13.5	2.5	0.2
Extraction Well	20.9	0.0	--
Event 4 - 13 Sep 92			
V1 - 5 ft.	13.0	9.0	--
V1 - 10 ft.	2.5	16.0	--
V2 - 5 ft.	5.5	10.0	--
V2 - 10 ft.	19.0	1.0	--
V3 - 5 ft.	2.0	8.0	--
V3 - 10 ft.	3.0	9.5	--
V4 - 5 ft.	21.0	0	--
V4 - 10 ft.	1.0	18.5	--
V4 - 15 ft.	17.0	3.0	--
V5 - 5 ft.	20.5	0.5	--
V5 - 10 ft.	18.0	5.5	--
V5 - 15 ft.	9.5	11.5	--

Table A-3
Analytical Data for Soil Samples

Location	Type	TPH	Gasoline	Diesel	Jet A	Benzene	Total BTEX
Sampling Event S1 -- 25 Jul 92							
V1-05	N	9.31	3.56	9.67	1.22	0.38	1.22
V1-10	N	6.99	5.62	4.93	2.52	0.64	1.77
V1-15	N	7.66	6.58	5.06	2.14	0.61	2.14
V2-05	N	12.82	8.91	10.14	6.5	0.56	0.88
V2-10	N	20.23	28.42	4.6	3.61	0.03	13.85
V2-15	N	183.3	14.39	234.5	99.37	7.35	38.45
V3-05	N	1396	530.7	1452	1035	13.71	90.57
V3-10	N	18.5	19.26	9.55	6.63	6.49	24.33
V3-15	N	1827	652.7	1934	1034	34.73	288.16
V4-05	N	4.66	1.52	5.04	< 1	0.69	2.72
V4-10	N	6.11	2.89	5.91	2.31	0.58	1.20
V4-10	FD	4.54	3.23	3.54	1.96	0.48	1.08
V4-15	N	4.43	2.81	3.72	< 1	0.48	1.47
V5-05	N	2.93	2.13	2.25	< 1	0.29	1.65
V5-10	N	4.96	3.65	3.77	< 1	0.68	1.44
V5-10	FD	4.86	4.35	3.07	1.93	0.60	1.24
V5-15	N	2.78	1.87	2.25	< 1	0.33	1.14
Sampling Event S2 -- 31 Aug 92							
V1-05	N	2.14	< 1	< 1	< 1	< 0.5	1.00
V1-10	N	6.61	9.34	< 1	2.76	4.1	12.7
V1-15	N	3.17	4.48	< 1	1.43	0.8	4.51
V1-15	FD	< 1	< 1	< 1	< 1	1.32	8.49
V2-05	N	8.82	1.7	8.95	< 1	< 0.5	1.76
V2-10	N	12.53	8.86	7.34	2.88	3.96	16.17
V2-15	N	173.1	< 1	203.3	128.1	3.39	27.58
V3-05	N	40.9	4.27	4.45	4.54	< 0.5	1.84
V3-10	N	855.9	329.9	730.6	728.5	1.24	14.52
V3-15	N	132.5	89.12	63.71	68.07	6.3	31.67
V4-05	N	< 1	< 1	< 1	< 1	< 0.5	1.00
V4-10	N	2.18	< 1	2.56	< 1	< 0.5	1.00
V4-15	N	3.86	< 1	< 1	< 1	< 0.5	1.00
V5-05	N	< 1	< 1	< 1	< 1	< 0.5	1.00
V5-10	N	< 1	< 1	< 1	< 1	< 0.5	1.00
V5-15	N	8.12	11.46	< 1	5.02	0.54	3.26

Table A-3
(Continued)

Location	Type	TPH	Gasoline	Diesel	Jet A	Benzene	Total BTEX
Sampling Event S3 -- 30 Sep 92							
V1-05	N	119	2.88	6.87	2.52	< 0.5	1.00
V1-10	N	108	5.36	8.2	1.3	< 0.5	2.10
V1-15	N	371	142	160	256	< 0.5	8.07
V2-05	N	677	165	515	707	< 0.5	2.71
V2-10	N	81.9	20.8	60.9	44.2	0.62	5.56
V2-15	N	217	22.3	250	230	< 0.5	1.63
V3-05	N	1495	1241	764	1453	5.17	131.97
V3-10	N	39.7	51	15.2	28.5	1.41	12.26
V3-15	N	695	215	508	740	.71	8.16
V3-15	FD	423	81.9	324	448	< 0.5	5.95
V4-05	N	8.81	< 1	4.64	< 1	< 0.5	1.00
V4-10	N	6.04	< 1	3.46	< 1	< 0.5	1.00
V4-15	N	150	< 1	6.03	2.82	< 0.5	1.00
V5-05	N	4.13	< 1	2.4	< 1	< 0.5	1.00
V5-05	FD	5.12	< 1	10.3	1.16	< 0.5	3.26
V5-10	N	3.83	< 1	2.4	< 1	< 0.5	1.00
V5-15	N	2.77	< 1	2.11	1.31	< 0.5	2.00

NOTES: Units = mg/kg. Type N = normal. Type FD = field duplicate.

APPENDIX A.3

Air Permeability Tests

Table A-4
Data From Air Permeability Test

Elasped Time	Readings by Location (in of H_2O)									
	V1-5	V1-10	V2-5	V2-10*	V3-5	V3-10	V4-5	V4-10	V5-5	V5-10
00:00:00	0	0	0	0	0	0	0	0	0	0
00:02:00	1.2	1.5	0.2	0	0.2	0.1	0	0.5	0.6	1
00:11:00	1.2	1.6	0.5	0	0.5	0.5	0.1	0.5	1	1.2
00:14:00	1.2	1.6	0.6	0	0.5	0.6	0.5	0.5	1	1.5
00:20:00	1.3	1.6	0.7	0	0.1	0.5	0.4	0.5	1	1.7
00:24:00	1.4	1.7	0.8	0	0.3	0.6	0.4	0.5	1	1.7
00:29:00	1.4	1.7	0.8	0	0.5	0.5	0.4	0.6	1	1.8
00:33:00	1.4	1.7	0.9	0	0.5	0.5	0.4	0.6	1	1.8
00:41:00	1.5	1.8	1	0	0.5	0.6	0.4	0.6	0.9	1.9
00:47:00	1.5	1.9	0.9	0	0.5	0.7	0.4	0.6	0.9	2.1
01:02:00	1.7	1.9	0.8	0	0.5	0.6	0.4	0.6	1	2.1
03:42:00	1.8	1.9	0.8	0	0.5	0.6	0.4	0.6	1	2.1

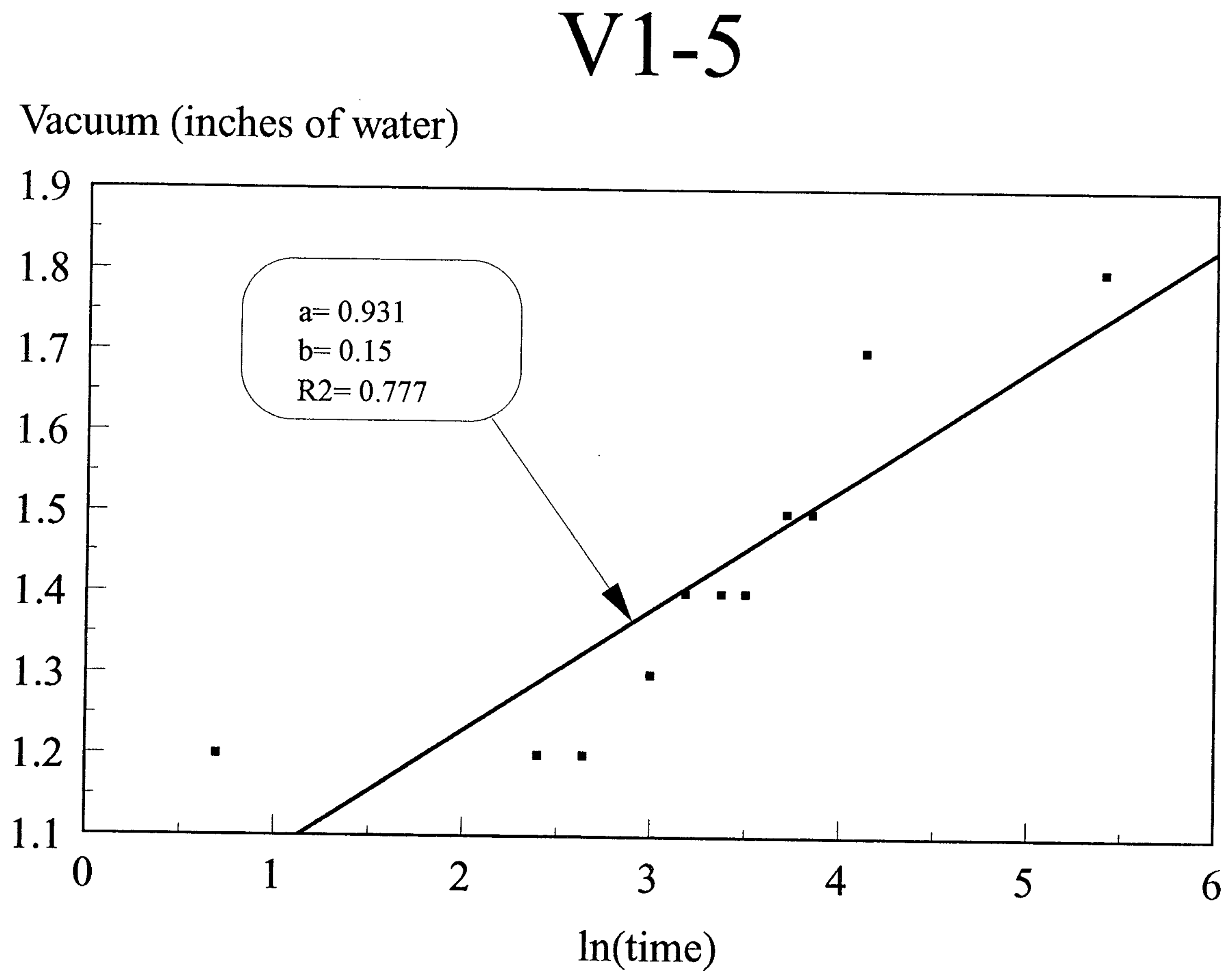


Figure A-4. Linear Regression Between Vacuum Measured and the Natural Logarithm of Elapsed Time (V1-5)

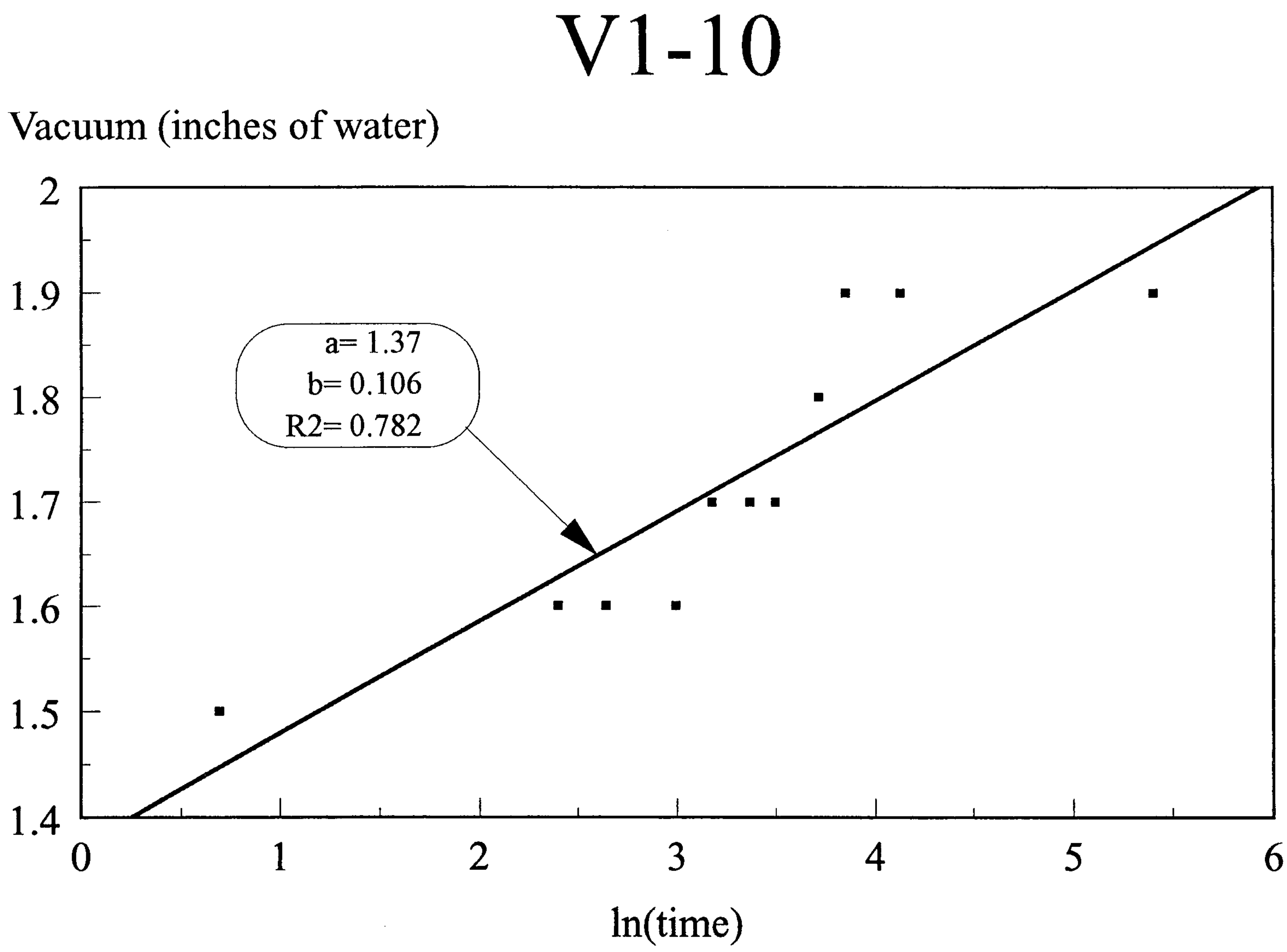


Figure A-5. Linear Regression Between Vacuum Measured and the Natural Logarithm of Elapsed Time (V1-10)

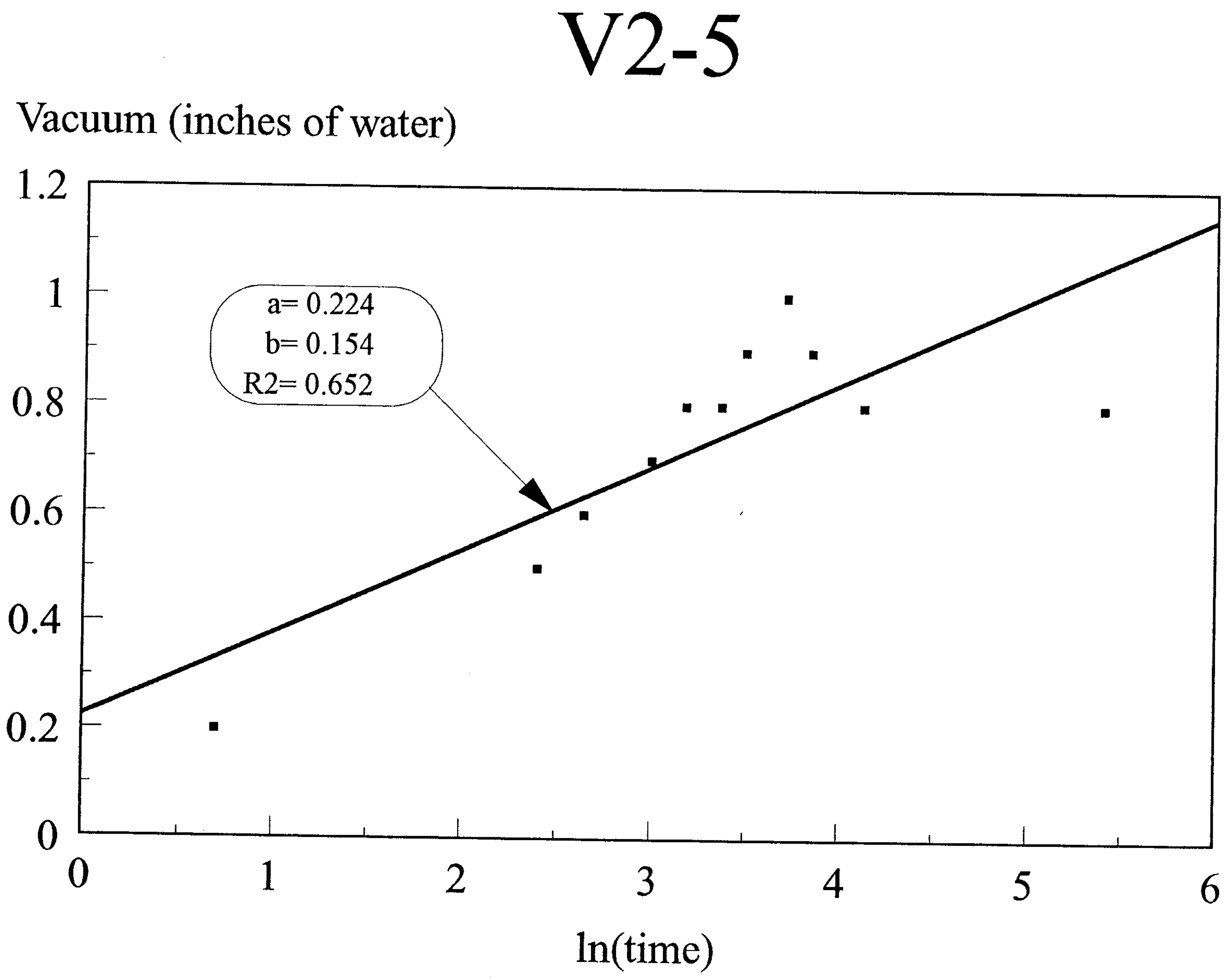


Figure A-6. Linear Regression Between Vacuum Measured and the Natural Logarithm of Elapsed Time (V2-5)

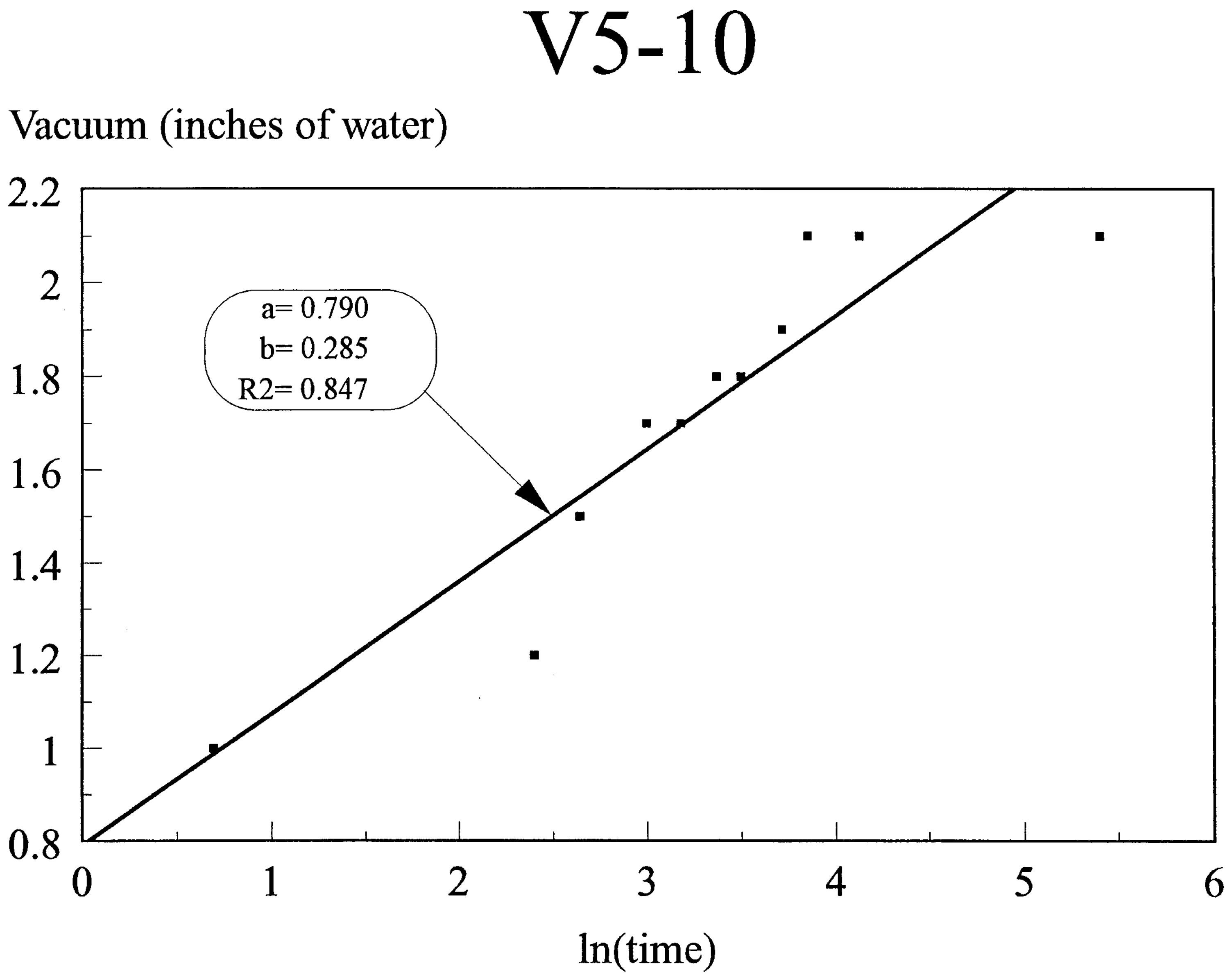


Figure A-7. Linear Regression Between Vacuum Measured and the Natural Logarithm of Elapsed Time (V5-10)

Table A-5
Results of Air Perm Test During the Phase I Pilot-Scale Test

	v1-5	v1-10	v2-5	v5-10	Average
Q (cm3/sec)	38166.67	38166.67	38166.67	38166.67	
A (g/cm-s2)/ln(min))	2316.328	3408.56	557.312	1965.52	
M (cm)	427	427	427	427	
u(g/cm-s)	0.00018	0.00018	0.00018	0.00018	
K (cm2)	5.53E-07	3.76E-07	2.30E-06	6.52E-07	9.70E-07
K (darcy's)	55.30179	37.581	229.8481	65.17211	96.97574

APPENDIX A.4

Soil Infiltration Tests

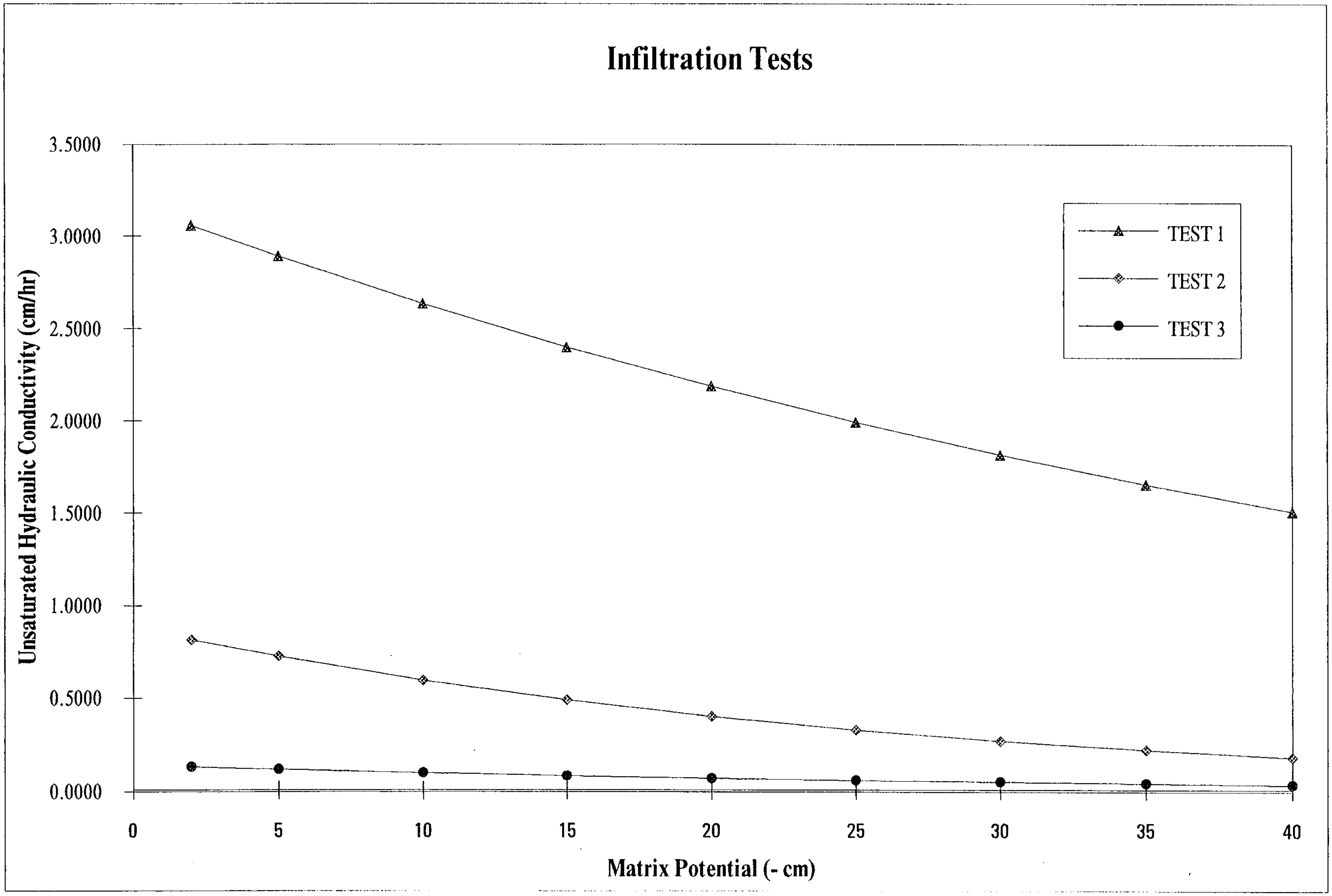


Figure A-8. Infiltration Rate as a Function Time for the Three Infiltration Tests

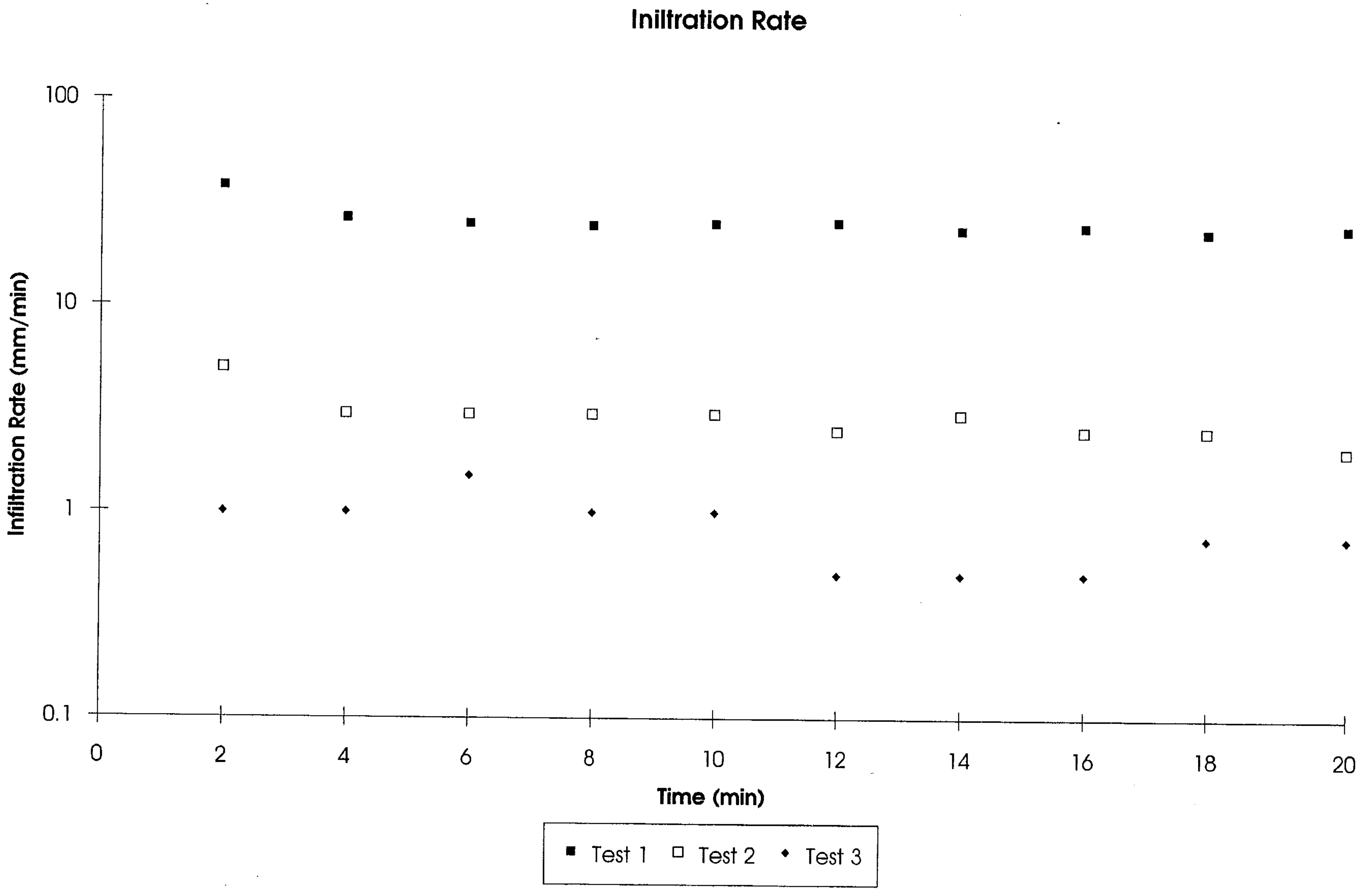


Figure A-9. Hydraulic Conductivity Relationships for Soils Tested in the POL Area

RADIAN CORPORATION

CALCULATION SHEET

CALC. NO.

SIGNATURE M.A. Robbins DATE 3/15/93 CHECKED JAR DATE 5/20/93

PROJECT GALENA T.S. JOB NO.

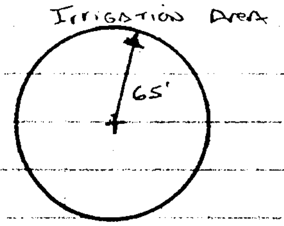
SUBJECT Infiltration Calculation SHEET 1 OF 1 SHEETS

Problem: Calculate WATER REQUIREMENT OF A NUTRIENT ADDITION IRRIGATION SYSTEM. THE SYSTEM will have A 65' FOOT RADIUS (130' dia) FOR AN AREA OF 13,273 FT^2.

Assume: 1) THE GROUND IS SATURATED AND WATER INFILTRATION IS AT STEADY state Therefore, THE SATURATED Hydraulic Conductivity IS APPROPRIATE.

2) THE SATURATED Hydraulic Conductivity is REPRESENTED BY THE AVERAGE OF THE 3 TESTS PERFORMED. SEE ATTACHED FIGURE.

Given:



$K_{SAT} = (3.17 + 0.88 + 0.14)/3$
$= 1.4$ cm/HR
$= 0.1046$ FT/HR

Attached. Figures 1 & 2

Volume of water required = 0.046 FT/hr * 13,273 FT^3
= 610 FT^3/hr
= 4,567 gallons/hr
= 109,622 gallons/day.

APPENDIX A.5

Hydrocarbon Removal Rates

RADIAN CORPORATION

CALCULATION SHEET

CALC. NO.

SIGNATURE MA Robbins DATE 3/19/93 CHECKED JAR DATE 5/20/93

ROJECT GALENA Treatability Study JOB NO.

SUBJECT HYDROCARBON REMOVAL RATES SHEET 1 OF 3 SHEETS

PROBLEM: Calculate the mass of Hydrocarbon Removed During the Operation of the SVE. Use concentrations in vapor phase measured at extraction well and periodically measured flow RATES.

Assumes

1) The the concentration in the vapor phase between sampling events can be Represented by the AVERAGE of the two concentrations.
2) The flow rate between measurements can be represented by a INTERPOLATION OF THE data points.
3) The mass of VOCs removed can be estimated the molecular weight of heptane (C_7H_{14}) as the representative hydrocarbon species.

EQUATIONS

$$\text{Vapor Concentration } (\text{ml-VPH}/\text{m}^3\cdot\text{Air}) * \frac{1\text{ mole}}{22.4\,\text{l}} * \frac{100\text{ g VPH}}{\text{mole}} * \frac{1\,\text{l}}{1000\text{ ml}} = (\quad \text{g}/\text{m}^3)$$

$$* \text{ Flow Rate } (\text{Ft}^3/\text{min}) * \frac{1\,\text{m}^3}{35.31\,\text{Ft}^3} * \frac{1440\text{ min}}{\text{DAY}} = \text{g}/\text{DAY}$$

DATA:

01 Aug 1910 ppm
> 3385

04 Aug 4860 ppm
> 2658

22 Aug 456 ppm
> 1553

05 Sep 2460 ppm
> 1305

27 Sep 150 ppm (1 Day AFTER Shut Down)

Flow:

From 50.5 Scfm ON 01 Aug to 81 ON 01 Sep to 79 ON 26 Sept

RADIAN CORPORATION

CALCULATION SHEET

CALC. NO.

SIGNATURE MA Robbins DATE 3/19/93 CHECKED DATE

PROJECT Galena Treatability Study JOB NO.

SUBJECT Hydrocarbon Removal Rate (Cont) SHEET 2 OF 3 SHEETS

Example Calculation:

ON 01 August: $^{\text{Avg}}C_v$ = 3385 ppmV

$$\text{Mass Removed, } M_R = 3385\ \frac{ml}{m^3} * \frac{1\ mole}{22.4\ l} * \frac{100\ g\ vph}{mole} * \frac{1\ l}{1000\ ml} = 15.11\ g/m^3$$

$$15.11\ g/m^3 * 50.5\ Ft^3/min * \frac{1\ m^3}{35.31\ Ft^3} * \frac{1440\ min}{Day} = \frac{31,122\ g}{Day}$$

$$= 31.1\ \frac{Kg\text{-}VPH}{Day}$$

$$= 68.5\ \frac{lbs\text{-}VPH}{Day}$$

SEE ATTACHED SPREADSHEET FOR Cumulative Removal Calculation!

Pg 3 of 3

Date	Well Concentration (ppm)	Est. Net Well Flow (scfm)	Est. VPH Removed (lbs)	Cumalative VPH Removed
01-Aug-92	3385	50.5	68.47	68.47
02-Aug-92	3385	53	71.86	140.33
03-Aug-92	3385	54	73.21	213.54
04-Aug-92	2658	55	58.55	272.09
05-Aug-92	2658	56	59.62	331.71
06-Aug-92	2658	57	60.68	392.40
07-Aug-92	2658	58	61.75	454.14
08-Aug-92	2658	59	62.81	516.96
09-Aug-92	2658	60	63.88	580.83
10-Aug-92	2658	61	64.94	645.78
11-Aug-92	2658	62	66.01	711.78
12-Aug-92	2658	63	67.07	778.85
13-Aug-92	2658	64	68.14	846.99
14-Aug-92	2658	65	69.20	916.19
15-Aug-92	2658	66	70.26	986.45
16-Aug-92	2658	67	71.33	1057.78
17-Aug-92	2658	68	72.39	1130.18
18-Aug-92	2658	69	73.46	1203.64
19-Aug-92	2658	70	74.52	1278.16
20-Aug-92	2658	71	75.59	1353.75
21-Aug-92	2658	72	76.65	1430.40
22-Aug-92	1553	72	44.79	1475.19
23-Aug-92	1553	73	45.41	1520.59
24-Aug-92	1553	74	46.03	1566.62
25-Aug-92	1553	75	46.65	1613.28
26-Aug-92	1553	76	47.27	1660.55
27-Aug-92	1553	77	47.90	1708.45
28-Aug-92	1553	78	48.52	1756.97
29-Aug-92	1553	79	49.14	1806.11
30-Aug-92	1553	80	49.76	1855.87
31-Aug-92	1553	81	50.38	1906.25
01-Sep-92	1553	81	50.38	1956.64
02-Sep-92	1553	81	50.38	2007.02
03-Sep-92	1553	81	50.38	2057.41
04-Sep-92	1553	80	49.76	2107.17
05-Sep-92	1400	80	44.86	2152.03
06-Sep-92	1400	80	44.86	2196.89
07-Sep-92	1400	80	44.86	2241.75
08-Sep-92	1400	79	44.30	2286.05
09-Sep-92	1400	79	44.30	2330.35
10-Sep-92	1400	79	44.30	2374.64
11-Sep-92	1400	79	44.30	2418.94
12-Sep-92	1400	78	43.74	2462.68
13-Sep-92	1400	78	43.74	2506.42
14-Sep-92	1400	78	43.74	2550.16
15-Sep-92	1400	78	43.74	2593.90
16-Sep-92	1400	78	43.74	2637.64
17-Sep-92	1400	78	43.74	2681.37
18-Sep-92	1400	78	43.74	2725.11
19-Sep-92	1400	78	43.74	2768.85
20-Sep-92	1400	78	43.74	2812.59
21-Sep-92	1400	78	43.74	2856.33
22-Sep-92	1400	78	43.74	2900.06
23-Sep-92	1400	78	43.74	2943.80
24-Sep-92	1400	78	43.74	2987.54
25-Sep-92	1400	78	43.74	3031.28
26-Sep-92	1400	78	43.74	3075.02
27-Sep-92	1400	78	43.74	3118.76

RADIAN
CORPORATION

CALCULATION SHEET

CALC. NO.

SIGNATURE J. A. Rehage DATE 5-20-93 CHECKED DATE 5/21/93

PROJECT Galena JOB NO.

SUBJECT Initial Mass of Hydrocarbons in POL study Area SHEET 1 OF 1 SHEETS

Calculate the mass of hydrocarbons present at the POL within the zone of influence of the SVE well. Use the soil concentrations determined in the initial round of samples for locations V1-V5.

NOTE: Wells V4 & V3 are outside the observed radius of influence but were used to calculate the average TPH concentrations. Additionally, the vertical depth to groundwater fluctuated between 5 & 15' during the course of the pilot study. Therefore the effective depth to GW is 10 feet.

avg. TPH, 5-ft. depth = 285 mg/kg
avg. TPH, 10-ft. depth = 9 mg/kg
avg. TPH, 15-ft. depth = 405 mg/kg

grand avg = 233 mg/kg

Assuming a radius of influence of 60 ft, and a depth of influence of 10 ft, the estimated mass of TPH is calculated below (assume a soil unit weight of 110 lb/ft^3).

$$\text{Vol. of Influence} = \pi r^2 h = \pi (60\,ft)^2 (10\,ft)$$

$$\text{Vol.} = 113{,}097\ ft^3$$

$$\mathrm{TPH}_{mass} = \begin{array}{c|c|c|c|c} 0.233\,g & kg & 110\,lb & 113{,}097\,ft^3 & kg \\ \hline kg & 2.2\,lb & ft^3 & & 1000\,g \end{array}$$

= 1317 Kg of TPH

= 2,899 lbs of TPH

APPENDIX B

Phase I Bench-Scale Test

Table of Contents

APPENDIX B.1

Experimental Methods and Procedures for the Phase I Bench-Scale Test

Description of Laboratory Procedures for the Bench-Scale Test

Preparation of Composite Sample for Biotreatability Test

A bulk sample of hydrocarbon-contaminated soil was collected from 10 to 17 ft below the original ground surface from the southeastern corner of the POL Tank Farm containment dike. Twenty-three 250-mL samples were collected with hand augers. The samples were stored on ice and shipped via express delivery to Radian's Microbiology Laboratory in Austin, Texas. Upon arrival, the samples were temporarily stored in a refrigerator at approximately 4° C prior to compositing. The composite sample was prepared by placing the 23 samples in a 5-gal. bucket, which was sealed (to minimize losses of volatile organic compounds [VOCs]) and tumbled by hand for 5 minutes. After compositing was completed, subsamples were withdrawn and submitted for the pretest analyses.

Pretest Analytical Characterization

The initial characterization program consisted of the identification and quantification of contaminants, including total petroleum hydrocarbons (TPH) and aromatic hydrocarbons [i.e., benzene, toluene, ethylbenzene, and xylenes (BTEX)]. The initial soils were also analyzed for nutrients (phosphorus and nitrogen), physical and chemical properties, and microbiological parameters (enumeration of total heterotrophic and hydrocarbon-utilizing microorganisms). Total viable bacteria (heterotrophic organisms) were counted using a non-selective culture medium, and hydrocarbon-utilizing organisms were enumerated using a medium that contained diesel fuel as the sole source of carbon.

Posttest Analytical Characterization

When the 97-day incubation period was over, the soils were analyzed to determine the residual levels of nutrients, TPH, BTEX, and microorganisms. These data were compared with the initial levels to determine how these parameters were affected by the various treatments tested.

General Approach — Respirometery Tests

Biotreatability effectiveness was assessed by measuring microbial respiration for the initial 65 days of the incubation period for each of the treatments tested. With the exception of using radiolabeled compounds, soil respirometry is perhaps the most efficient method to quantitatively determine to what extent hydrocarbons present in soil will biodegrade under conditions suitable for microbiological growth. The procedure consists of adding a known amount of hydrocarbon-contaminated soil to a biometer flask. Oxygen uptake or consumption (i.e., biological oxygen demand) and carbon dioxide evolution in the closed flask are measured with time in order to indirectly assess the biodegradability of the hydrocarbon contaminants.

The respirometry procedure was used to determine the effects of several treatment conditions. Each of the treatments, including the barometric control, was incubated in a refrigerator at 2° to 5° C for the duration of the experiment. The respirometry tests were carried out in biometer flasks; the apparatus is shown in Figure B-1. Each flask was sparged daily with a gas stream composed of a specific O_2 concentration for 2 minutes, which was a sufficient length of time to completely flush the respirometer flask.

Treatment Conditions

Several treatment conditions were chosen to evaluate biotreatment performance.

Table B-1 outlines the specifications of each of the treatments tested and includes the amount and frequency of any added amendments. The mass of soil added was adjusted for moisture content to achieve 1000 g of dry soil. The procedures for determining the flask constants and for loading the flasks are described in the work plan.

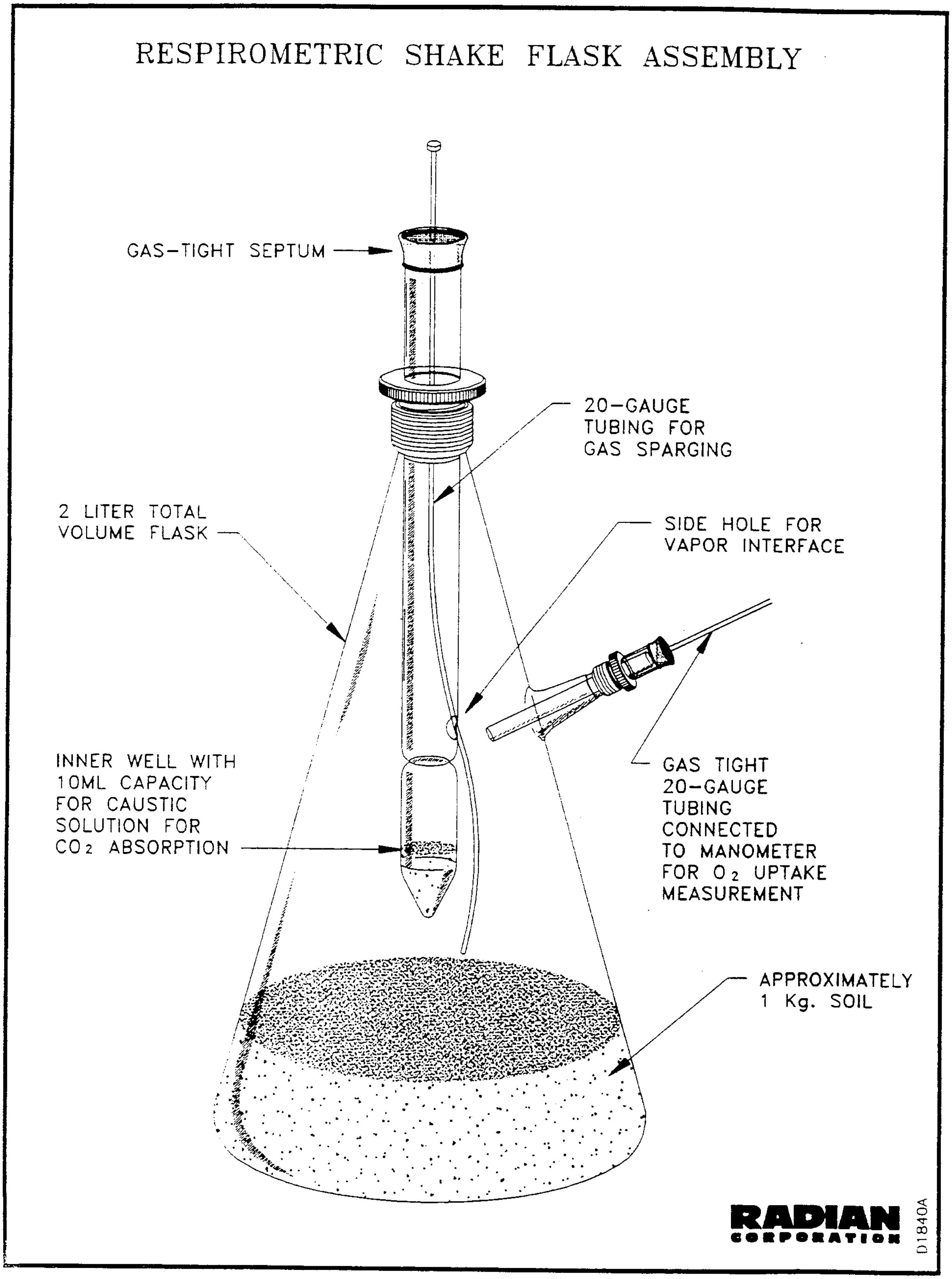


Figure B-1. Schematic Diagram of the Biometer Flask Used in the Respirometry Study

Table B-1
Biotreatability Flask Test Specifications

Treatment	O_2 (%)	Soil Mass[1] (g)	Amendments	Amendment Addition	Frequency
1 - Contaminated Soil	21	1160.4	---	---	---
2 - Contaminated Soil	14	1161.5	---	---	---
3 - Contaminated Soil	7	1167.2	---	---	---
4 - Contaminated Soil	2	1160.2	---	---	---
5 - Contaminated Soil + Nutrients	21	1161.4	NH_4NO_3	0.655 g	Initially
			KH_2PO_4	0.378 g	Initially
			Hoagland's[2]		Initially
6 - Contaminated Soil + Nutrients under H_2O saturated conditions	21	1160.2	NH_4NO_3	0.655 g	Initially
			KH_2PO_4	0.378 g	Initially
			Hoagland's		Initially
			DI water	48.8 g	Initially
7 - Contaminated Soil + Nutrients + Commercial Inoculum	21	1161.5	NH_4NO_3	0.655 g	Initially
			KH_2PO_4	0.378 g	Initially
			Hoagland's		Initially
			Inoculum[3]	6 ml	Weekly

[1] Quantity of soil on a wet basis that equals 1000 g of dry weight soil.

[2] Hoagland's solution added to achieve appropriate concentrations of macronutrients on a per kilogram basis.

[3] Twelve grams of commercial inoculum added initially followed by a 6-gram weekly addition.

The contaminated soil with no amendments under normal atmospheric conditions was treated first. This treatment measured indigenous microbial activity at 21% O_2 with no nutrient addition and was used as a basis for comparison for the other unamended treatments at subatmospheric levels of oxygen.

In the second, third, and fourth treatments, the activity of the indigenous microorganisms at reduced oxygen concentrations (14%, 7%, and 2%, respectively) was evaluated. These treatment conditions were used to evaluate the effect of reduced oxygen levels on microbial respiration. Field measurements at Galena Airport and other hydrocarbon-contaminated sites indicate that oxygen decreases with soil depth to levels as low as 2 percent.

Contaminated soil amended with nutrients at 21% O_2 was the fifth treatment condition. This condition was used to measure respiration associated with biodegradation of soil contaminants by indigenous bacteria that have been given additional macronutrients (nitrogen and phosphorus) and a standard micronutrient solution of trace elements. The levels of nitrogen and phosphorus added were based on the initial concentrations of carbon, nitrogen, and phosphorus. Nutrients were added to attain a C:N:P ratio of approximately 60:2:1.

The sixth treatment condition was the same as the fifth treatment, except that the contaminated soil was saturated with water; this condition could lead to reduced oxygen conditions caused by water-logging. This treatment represented subsurface conditions typical of soils below the water table.

The seventh treatment condition evaluated was similar to Treatment 6, but with the addition of hydrocarbon-degrading microorganisms produced by Solmar Corp. (Orange, CA). The purpose of this treatment evaluation was to determine if any benefit might be gained by bioaugmentation using a commercial microorganism consortium, which is reported to be effective in degrading the hydrocarbons of concern. The Solmar product contains a proprietary mixture of bacteria and microfungi (yeast) formulated to degrade petroleum hydrocarbons. The cultures were attached to a bran substrate that was rehydrated before being added to the flask.

This resulted in soils that were saturated with water. The amendment was added at the beginning of the study and weekly thereafter, as recommended by the manufacturer.

Respirometry Measurements

Microbial respiration was monitored by measuring both O_2 consumption and CO_2 evolution.

Oxygen Consumption—Oxygen uptake was measured manometrically for each of the treatments and the barometric control on a daily basis. The barometric control was subtracted from each of the treatment readings and total oxygen consumption was calculated as described in the work plan. Data were plotted as cumulative mmol of O_2 consumed per kg of dry soil as a function of incubation time.

Carbon Dioxide Evolution—Carbon dioxide evolution was measured for each treatment and for the barometric control (which consisted of sterile ground glass instead of soil) by absorbing respired CO_2 in a standard potassium hydroxide (KOH) solution, precipitating the absorbed CO_2 with $BaCl_2$, and titrating the remaining KOH solution with HCl.

The KOH solution was held in the inner well of the air-tight biometer flask. CO_2 is absorbed by the following reaction:

$$CO_{2\,(g)} + KOH \rightarrow K_2CO_3 + H_2O.$$

The amount of CO_2 evolved was determined indirectly by measuring the unreacted KOH in the respirometer well. The absorbed CO_2, present as CO_3^{2-}, was removed by precipitation as $BaCO_3$; the unreacted KOH was titrated using a standard solution of HCl with phenolphthalein as an end-point indicator. The amount of KOH used to absorb evolved CO_2 was then determined by the difference of the initial and unreacted KOH in the inner well. The amount of CO_2 evolved was then calculated using the molar relationship between CO_2 absorbed by the KOH. The levels of carbon dioxide evolved from each of the treatment flasks (after subtracting the CO_2 in the barometric control) were plotted as cumulative mmol of CO_2 evolved per kg of dry soil as a function of incubation time.

APPENDIX B.2

Analytical Results for the Phase I Bench-Scale Test

Table B-2
Bacterial Enumeration Pre- and Postlaboratory Treatability Study

Sample	Heterotrophic Bacteria (CFU/gm)	Hydrocarbon Utilizers (CFU/gm)
Composite (pre-treatment)	5.3×10^7	3.8×10^3
G-unamended soil, 21% O_2	9.6×10^7	5.6×10^5
H-unamended soil, 14% O_2	9.4×10^7	6.9×10^3
I-unamended soil, 7% O_2	1.2×10^8	1.1×10^3
J-unamended soil, 2% O_2	1.6×10^8	3.8×10^3
K-contaminated soil + nutrients 21% O_2	1.7×10^6	5.3×10^5
L-contaminated soil + nutrients, water saturation, 21% O_2	1.5×10^8	1.5×10^6
M-contaminated soil + nutrients + Inoculum, 21%	4.0×10^7	$>10^7$

Table B-3
Initial Soil Characterization Results

Analyte	Sample #1	Sample #1 Dup	Sample #2
Moisture, %	11.6	11.6	12.7
pH	8.3	8.3	8.1
TOC, %	0.5	0.6	0.7
Sand, %	89.8	89.7	83.1
Silt, %	6.5	6.9	14.7
Clay, %	3.7	3.5	2.3
TPH-GC, ppm	978	1,015	1,172
Benzene, ppm	6.98	6.15	9.73
Toluene, ppm	42.60	45.16	51.96
Ethylbenzene,ppm	16.93	17.50	17.52
Xylenes, ppm	61.36	60.34	62.40

Table B-4
BTEX Results Under Varying Test Conditions

Sample	TPH ppm	Benzene ppm	Toluene ppm	Ethylbenzene ppm	Xylenes ppm
G-unamended soil, 21% O_2 duplicate	279.9	<0.50	1.32	<0.50	1.17
G-unamended soil, 21% O_2		<0.50	1.80	<0.50	2.42
H-unamended soil, 14% O_2	430.6	1.52	2.12	<0.50	2.34
I-unamended soil, 7% O_2	456.2	1.45	2.03	<0.50	2.93
J-unamended soil, 2% O_2	398.7	<0.50	2.56	<0.50	2.49
J-unamended soil, 2% O_2 duplicate	376.8				
K-contaminated soil + nutrients 21% O_2	555.5	<0.50	14.83	4.15	24.54
L-contaminated soil + nutrients, water saturation, 21% O_2	546.5	<0.50	7.33	1.89	12.18
M-contaminated soil + nutrients + Inoculum, 21%	346.9	<0.50	6.51	1.81	11.42

APPENDIX B.3

Calculations for Degradation Rates for the Phase I Bench-Scale Test

Biodegradation Rate Calculation

Degradation rates of hydrocarbon contaminants for the various bench-scale treatments were determined by two methods: 1) calculation of the TPH removed with time, and 2) estimation of hydrocarbon degradation using a stoichiometric relationship.

In the first method, the levels of TPH determined by chemical analysis of the soil before and after treatment were used to calculate the TPH degration rate (K_{CB}) over the incubation period using the following equation:

$$K_{CB} = (TPH_i - TPH_f)/t, \tag{1}$$

where: TPH_i = initial TPH concentration before treatment (1055 mg/kg);
TPH_f = final TPH concentration after treatment; and
t = incubation time (97 days).

The second method involved estimating the amount of hydrocarbon degraded as determined by the stoichiometric ratio of O_2 consumption and degradation of a representative hydrocarbon. Although a similar estimation is possible using the ratio of CO_2 produced and hydrocarbon degraded, this approach was not used because of the apparent incomplete degradation of the parent hydrocarbon contaminants as evidenced by the low ratio of CO_2 evolved to O_2 consumed. Heptane was selected as the representative hydrocarbon on the basis of chemical analysis, so the equation relating O_2 consumption to hydrocarbon degradation is as follows:

$$C_7H_{16} + 11O_2 = 7\ CO_2 + 8\ H_2O. \tag{2}$$

On the basis of the oxygen uptake rates and the stoichiometric relationship of O_2 consumed and hydrocarbon degraded from equation 2, the biodegradation rate (K_{EB}) was estimated as follows:

$$K_{EB} = K_o M/R, \qquad (3)$$

where: K_0 = oxygen uptake rate (mmol/kg/day);

R = molar ratio of O_2 consumed to hydrocarbon oxidized (11/1); and

M = molecular weight of heptane (100.2 mg/mmol).

RADIAN
CORPORATION

CALCULATION SHEET

CALC. NO. 1

SIGNATURE Greg DATE 3/25/94 CHECKED Jim Rebeze DATE 5-10-94

PROJECT Galena TS JOB NO.

SUBJECT Example Calculations for Bench-Scale Study SHEET 1 OF ~~8~~ 5 JR SHEETS

Calculation of % TPH Degraded and TPH Degradation Rates for Various Bench Scale Treatments using TPH Analytical Data

Treatment # 1: 21% O_2 (no amendments)

Initial TPH = 1055 mg/kg
Final TPH = 279.9 mg/kg
Treatment Time = 97 days

$$\%\,\text{TPH Degraded} = \frac{1055\ \text{mg/kg} - 279.9\ \text{mg/kg}}{1055\ \text{mg/kg}} \times 100\%$$

$$= 73.46\%$$

$$\text{TPH Degradation Rate} = \frac{1055\ \text{mg/kg} - 279.9\ \text{mg/kg}}{97\ \text{days}}$$

$$= 8.0\ \text{mg/kg/day}$$

(see attached spreadsheet for calculations for remaining six treatments)

Pg 2 of 5

Calculation of %TPH Degraded and Degradation Rates for Various Bench Scale Treatments using TPH Analytical Data

%TPH Degraded = ((Final TPH - Initial TPH)/Initial TPH)*100%
*TPH Degradation Rate = (Final TPH - Initial TPH)/time
*Degradation rates calculated assuming zero-order kinetics which were displayed by the respirometry data

Treatment	Final TPH (mg/Kg)	% TPH Degraded	TPH Degradation Rate (mg/Kg/day)
#1 - 21% O2	279.9	73	8.0
#2 - 14% O2	430.6	59	6.4
#3 - 7% O2	456.2	57	6.2
#4 - 2% O2	398.7	62	6.8
#5 - 21% O2 + N	555.5	47	5.1
#6 - Sat 21% O2 + N	546.5	48	5.2
#7 - Sat 21% O2 + N,I	346.9	67	7.3

Initial TPH (mg/Kg)	1055
Time (days)	97

APPENDIX C

Phase II Pilot-Scale SVE/Sparging Test

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APPENDIX C.1

Well Construction Diagrams

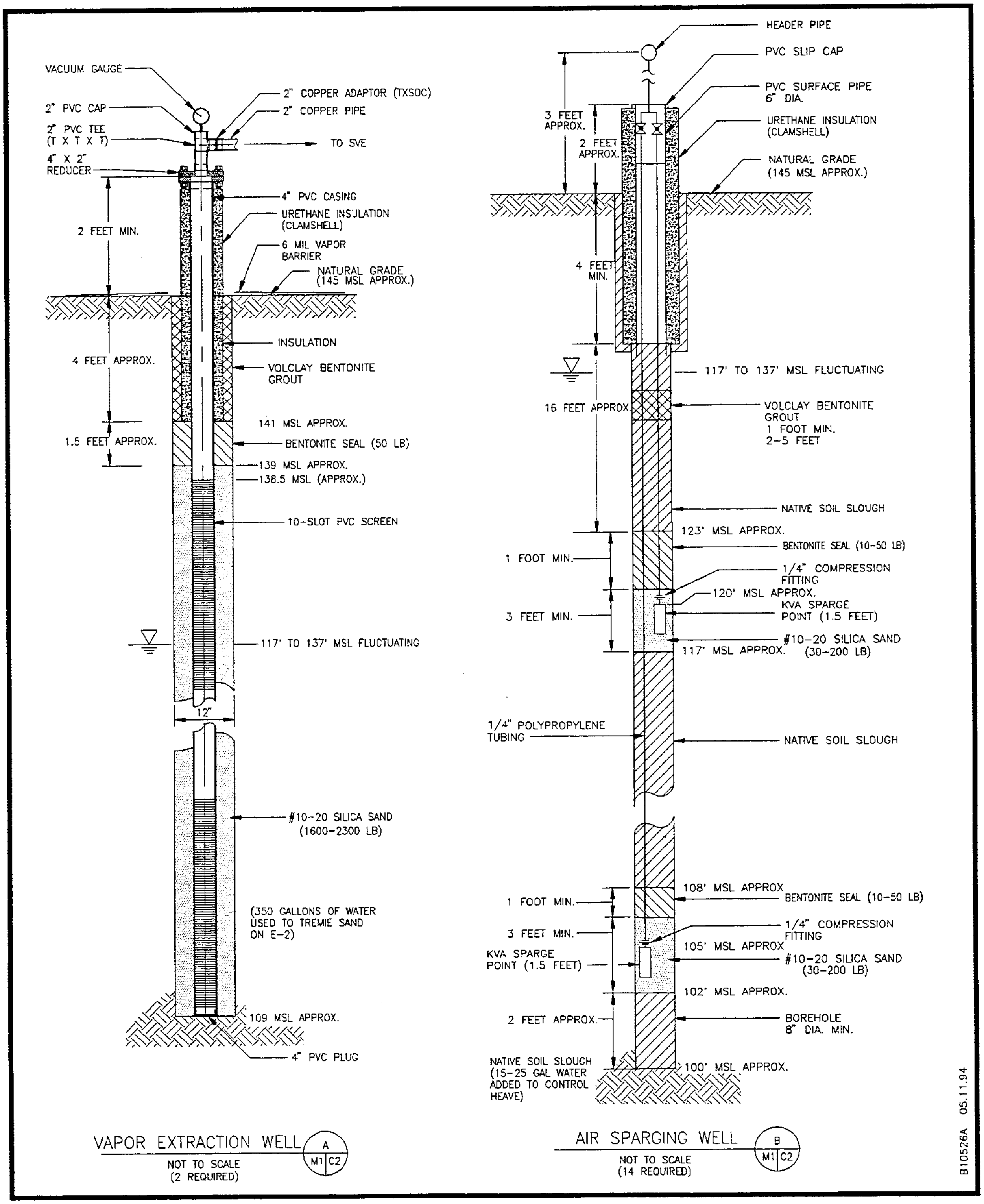

Figure C-1. Well Diagrams for the Vapor Extraction and Air Sparging Wells

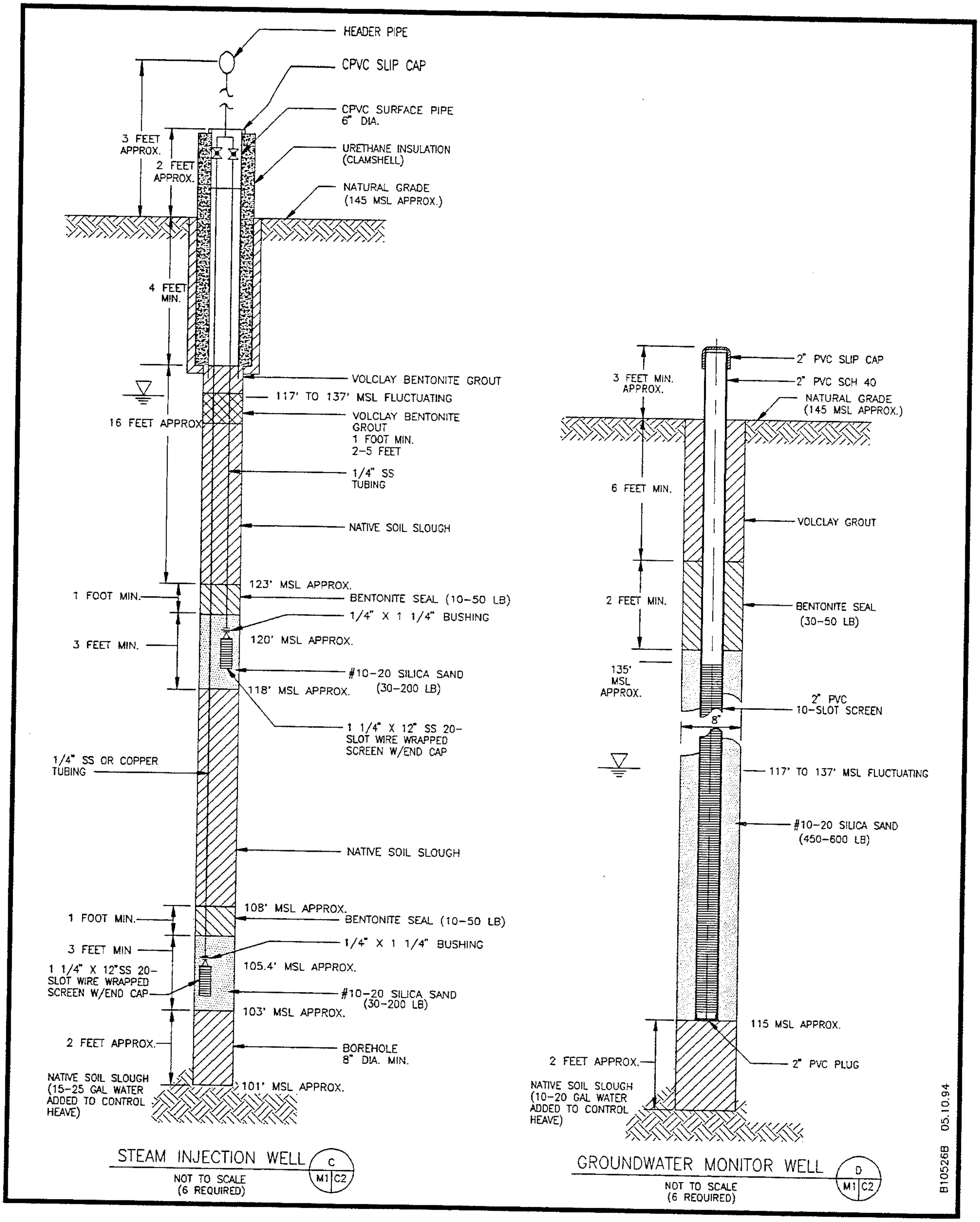

Figure C-2. Well Diagrams for the Steam Injection and Groundwater Monitor Well

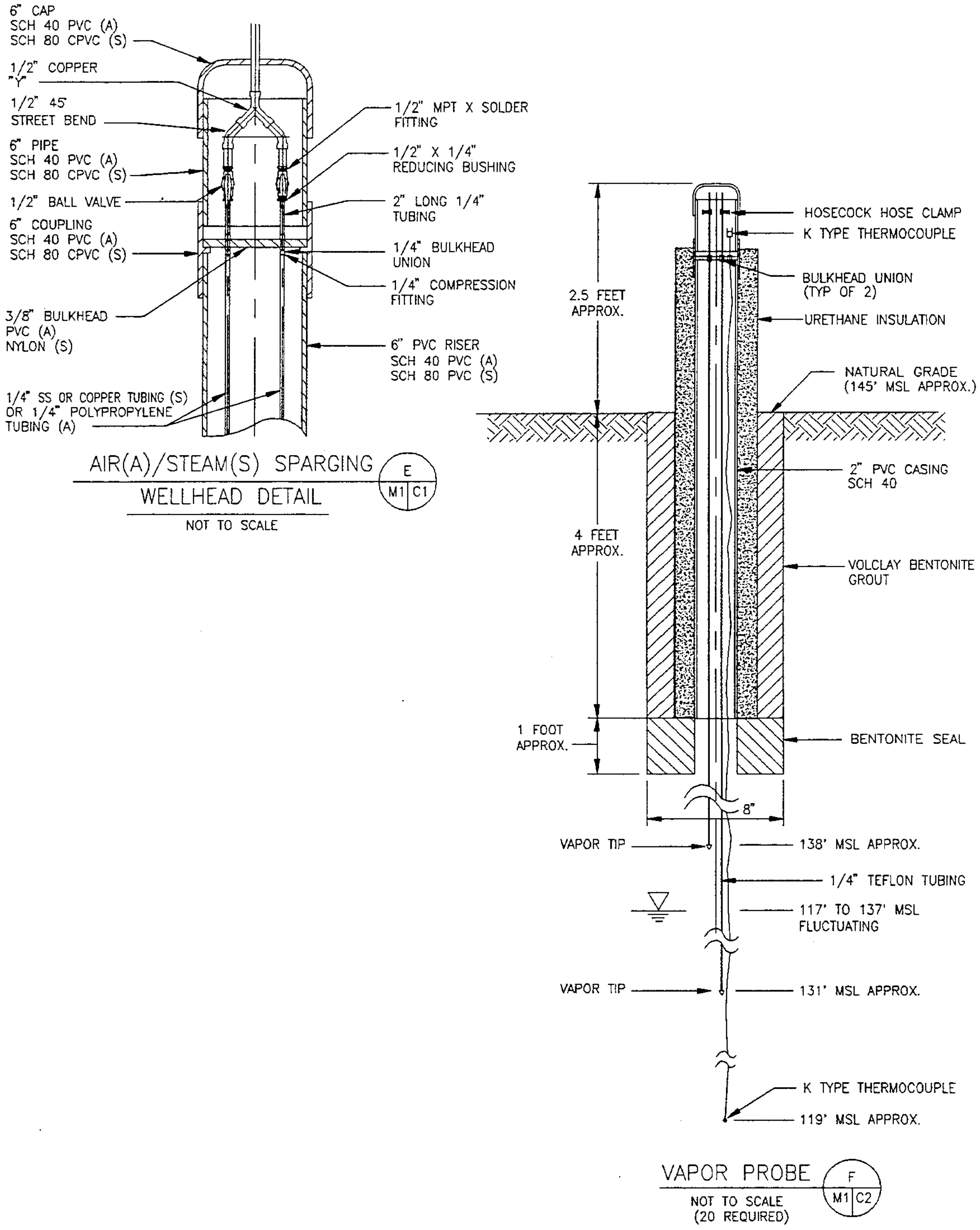

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Figure C-3. Construction Diagram for the Sparging Wellhead and the Vapor Probe

APPENDIX C.2

Sampling and Analytical Methods
and
Analytical Results

Table C-1
Analytical Procedures and Estimated Detection Limits for Soil, Water, and Air Analyses

Parameter	Method	Detection Limit		
		Soil	Air	Groundwater
Percent Moisture	ASTM[a] D2216	DNA	NA	NA
pH	EPA SW-846[b] 9045	DNA	NA	DNA
Electrical Conductivity	EPA 600/4-79[c] 120.1	.01 mmhos/cm	NA	0.01 mmhos/cm
Nitrate-Nitrogen	Am. Soc. Agro.[d] 33-8.3	15 mg/kg	NA	1 mg/L
Ammonia-Nitrogen	Am. Soc. Agro. 33-7.3	5 mg/kg	NA	1 mg/L
Phosphate-Phosphorus	TAES STP IV and V[e]	5 mg/kg	NA	1 mg/L
Total Petroleum Hydrocarbons	EPA SW-846 Modified 8015	1 mg/kg (gasoline range) 10 mg/kg (diesel range and heavier)	NA	0.1 mg/L (gasoline range) 1.0 mg/L (diesel range and heavier)
Total Nonmethane Hydrocarbons and Volatile Organic Compounds	EPA 600/4-87[f] Modified TO 14	NA	0.3 ppbV (total) Variable (VOCs)	NA
Total Nonmethane Hydrocarbons	EPA 600/4-87 Modified TO 12	NA	0.3 ppbV	NA
Total Organic Carbon	Am. Soc. Agro. Modified 29-2.2.4	0.1%	NA	NA
Heterotrophic Plate Count	Am. Soc. Agro. 37	300 cells/g	NA	300 cells/mL
Hydrocarbon Utilizing Bacterial Count	Am. Soc. Agro. 37	300 cells/g	NA	300 cells/mL
Carbon dioxide (field measurement)	GasTech[g] Manual	NA	0%	NA

Table C-1
(Continued)

Parameter	Method	Detection Limit		
		Soil	Air	Groundwater
Oxygen (field measurement)	GasTech Manual (air)/YSI Manual [h] (groundwater)	NA	0%	0% or 0 mg/L
Temperature (field measurement)	DIGI-SENSE® Manual [i]	-190°C	NA	NA
Volatile Organic Compounds (field measurements)	Thermo PID Manual [j]	NA	0.2 ppm	NA
	Heath FID Manual [k]	NA	0.1 ppm	NA
Total Petroleum Hydrocarbons (field measurement)`	GAC Portable IR [l]	1 mg/kg	NA	1 mg/L

DNA = Detection limit not applicable.
NA = Not analyzed.

[a] American Society for Testing and Materials. *Annual Book of ASTM Standards.* November 1987.
[b] U.S. Environmental Protection Agency. *Test Methods for Evaluating Solid Waste.* Third Edition. SW-846, 1986.
[c] U.S. Environmental Protection Agency. *Methods for the Chemical Analysis of Water and Wastes.* EPA-600/4-79-020. March 1983.
[d] American Society of Agronomy, Inc. *Methods of Soil Analysis, Part 2, Chemical and Microbiological Properties.* 2nd Edition, 1982.
[e] Texas Agriculture Extension Service. *Soil Testing Procedures.*
[f] U.S. Environmental Protection Agency, *Compendium of Methods for the Determination of Trace Organic Compounds, in Ambient Air.* EPA-600/4-87/006, May 1988.
[g] Gas Tech, Inc. Instruction Manual—*GasTechtor Carbon Dioxide/Oxygen Indicators Model 3252OX.*
[h] YSI Incorporated. *YSI Model 50B Dissolved Oxygen Meter Instructions.*
[i] Cole-Palmer Instrument Co. *Model No. 8528-101(JTEK) Manual A-1299-258,* edition 1188.
[j] Heath Tech. *Instruction Manual for Heath Detcto-Pak® III,* Heath Consultants Incorporated.
[k] Thermo Environmental Instruments Inc. OVM/Datalogger Model 580B.
[l] General Analysis Corporation. "Field Procedure using GAC TPH Analyzer."

Table C-1A
Monitoring Schedule for the Phase II Pilot-Scale Test

Event	Sampling (Days)	Matrix	Field Analyses	Field Samples[b]	Field Duplicates[b,c]	PA Samples[b]	Analytes
G0	0	Gas	18	18	2	1	VOCs*, O_2*, CO_2, TNMHC, BTEX
G1	5	Gas	18	2	2	0	VOCs*, O_2*, CO_2, TNMHC, BTEX
G2	15	Gas	36	4	1	1	VOCs*, O_2*,CO_2, TNMHC, BTEX
G3	30	Gas	36	6	0	0	VOCs*, O_2*,CO_2, TNMHC, BTEX
G4	60	Gas	33	29	4	0	VOCs*, O_2,*CO_2, TNMHC, BTEX
G5	90	Gas	26	4	2	0	VOCs*, O_2,*CO_2, TNMHC, BTEX
G6	120	Gas	38	3	1	1	VOCs*, O_2,*CO_2, TNMHC, BTEX
G7	150	Gas	27	5	0	0	VOCs*, O_2*,CO_2, TNMHC, BTEX
G8	180	Gas	31	28	3	1	VOCs*, O_2*,CO_2, TNMHC, BTEX
S0	0	Soil	12	24	3	0	TPH, DRO, GRO, BTEX, TRPH*, Moisture, EC, NO_3, NH_4, PO_4, TOC, Microbial counts
S1	30	Soil	0	12	0	0	TPH
S2	60	Soil	0	12	1	0	TPH, DRO, GRO, BTEX, Moisture, Microbial counts
S3	90	Soil	0	12	0	0	TPH
S4	120	Soil	0	12	0	0	TPH, DRO, GRO, BTEX, Moisture, Microbial counts
S5	150	Soil	0	12	1	0	TPH
S6	180	Soil	0	12	1	0	TPH, DRO, GRO, BTEX, Moisture, EC, NO_3, NH_4, PO_4, TKN, pH, TOC, Microbial counts
W0	0	GW	8	8	1	0	DO*, TPH, DRO, GRO, BTEX, TRPH*, Microbial counts, NO_3, NH_4, PO_3
W1	30	GW	8	0	0	0	DO*, TRPH*
W2	60	GW	8	0	0	0	DO*, TRPH*
W3	90	GW	8	0	0	0	DO*, TRPH*
W4	120	GW	8	0	0	0	DO*, TRPH*, Microbial counts
W5	150	GW	8	0	0	0	DO*, TRPH
W6	180	GW	8	0	1	0	DO*, TPH, DRO, GRO, BTEX, Microbial counts, NO_3, NH_4, PO_4

Notes: *Field measurement. [a]G = Gas sampling event, S = soil sampling event, W = groundwater sampling event. [b]Sample collected for off-site laboratory analysis. [c]Field duplicates are replicate samples for quality assurance analysis. BTEX = Benzene, toluene, ethylbenzene, xylenes. DRO = Diesel-range organics. EC = Electrical conductivity. GRO = Gasoline-range organics. GW = Groundwater. PA = Performance audit (calibration goals used for quality assurance analysis). TKN = Total Kjeldahl nitrogen. TNMHC = Total non-methane hydrocarbons. TPH = Total petroleum hydrocarbons. TOC = Total organic carbon. TRPH = Total recoverable petroleum hydrocarbons. VOCs = Volatile organic compounds.

SAMPLING PROCEDURES

Gas Sampling

- Calibrate the TraceTechtor hydrocarbon analyzer with 4400 ppm hexane that came in the calibration kit from GasTech. Record the calibration in the treatability study (TS) logbook #3. The instrument was last calibrated in the "full methane response" mode. Either mode is fine but be consistent. If it is calibrated in the full methane response mode, then the readings should be taken in the full methane response mode. The calibration procedures are discussed in the TraceTechtor manual, which is in the gray file box in the office. Also, there should be some literature with the calibration kit from GasTech.

- Calibrate the O_2/CO_2 analyzer using ambient air, 99.99% nitrogen, and 5% CO_2. Record the calibration in the TS logbook #3. The instruction manual for this analyzer should also be in the gray file box. Some of the calibration screws are internal; they are accessible by unscrewing the bolt in the back of the analyzer and lifting the top gently from the bottom. There is a toggle switch on the instrument that sets the analyte, O_2 or CO_2. The instrument should be set to zero for both O_2 and CO_2 with the nitrogen (Scotty III cylinder). Then, calibrate the instrument to 5% CO_2 with the other Scotty gas cylinder. There is only one regulator for the Scotty cylinders. The instrument should be calibrated to 21% O_2 using ambient air.

- Check the accuracy of the two short thermocouples (labeled east and west) and the downhole thermocouple using an ice bath. Record the readings in the TS logbook #3.

- Take total hydrocarbon (THC) with the TraceTechtor, O_2, and CO_2 readings for the soil vapor extraction (SVE) exhaust gas lines on the east and west SVE units and record the imnformation on the Field Soil Gas Data and Sample Log Form. Also, record the temperature of the SVE exhaust. The west SVE is sample location E-1, and the east SVE is E-2. The west exhaust gas should be >10,000 ppm. There is a dilution fitting that connects to the TraceTechtor between the filter and the instrument. This attachmnet dilutes the measured concentrations by 50%, so double the reading on the insturnment to determine the actual concentration in the gas. The first dilution fitting was a factory defect, so you may want to check the accuracy of the dilution fitting by measuring the concentration in the exhaust on the east side with and without the fitting.

- Take a canister sample from each SVE exhaust. Sample IDs should start with 05-G4-01. Take duplicate canister samples from the SVE exhausts, as well. Clearly mark on both chain of custodies (COCs) that these samples are duplicates of each other. Also, clearly state "Run nested duplicate" on the COC for these four samples.

- To prepare the canisters for sampling, make sure both valves are closed before removing the plugs. Then connect a filter sent with the canister to one port. Connect the small 30 in. Hg vacuum gauge to the other port. Use the piece of stainless steel 1/4 in. tubing with one swagelok end and one tubing end (found in the east enclosure) to connect the vapor probe to the canister. There is a memo on VOC sampling in the gray file box. Be diligent about filling out the paperwork--both the canister tags and the COCs.

- To take a canister sample, open the valve to the vacuum gauge. Record the initial vacuum on the canister tag and in the logbook. If the initial vacuum is less than 25 in. Hg, do not use the canister. Mark the COC and the canister tag with "Insufficient vacuum; Do not analyze." Very slowly open the other valve to begin sampling. Caution: only the slightest turn of the valve is required to achieve the desired flow rate. The sample should be taken over several minutes (3 to 5). The sample rate can be adjusted with the valve. Close the sample valve when the vacuum gets around 5 in. Hg and record the final vacuum on the canister tag after the sample is taken. Also, record the elapsed time for sample collection on the log form. Close the valve with the vacuum gauge and remove the gauge. The valves should be closed hand tight. Take the filter off and replace the plugs on the two valves. The plugs help prevent the loss of the sample if the valves were to come open during transport.

- After the SVE exhaust lines have been sampled, you are ready to begin sampling the vapor wells. Turn off both SVE units. All of the shallow and deep vapor wells should be sampled except for V-17S and V-11S. Wells V-14S, V-12S, and V-10S may be filled with water. During the last sampling event, silty groundwater was pulled up through the tubing while trying to sample these points. If the groundwater table is not below 129 to 130 ft. MSL, then the deep vapor wells are submerged and cannot be sampled. The elevation at the site is around 144 to 149 ft. MSL.

- The vapor probes need to be purged before sampling. Use the peristaltic pump (which Brian brought) to purge the vapor probes for 2 minutes prior to taking measurements. The sample flow rate should be around 500 mL/min. This corresponded to a 5 to 6.5 setting on the controller during the last sampling event. This pump is different, but the head is the same so this setting may still be right. To check the flow, connect the bubble meter to the outlet of the pump. Be very careful with the bubble meter because it is not ours and is expensive to replace. Turn on the meter (it takes a minute to turn on) and squeeze the bulb to get a bubble to travel up the glass cylinder. The meter will read the flow in L/min. After you have the flow rate set, remove the flow meter form the system and purge the vapor line for approximately 2 minutes. Remember to clamp the vapor probe tubing whenever it is not in use.

- Using the peristaltic pump to deliver gas to the instruments, take measurements with the TraceTechtor and O_2/CO_2 analyzer and record on the data form. After these readings are recorded, take a canister sample as described above.

- Take temperature measurements with the digital thermometer for the vapor wells with deep thermocouples. For at least three shallow probes in each test cell, insert the shallow thermocouple into the shallow vapor probe tube and take temperature readings. There is a separate thermocouple for each test cell (east and west) to prevent cross-contamination.

- Take duplicate canister samples from two separate vapor wells. Choose samples from probes which have THC concentrations in the 100 to 1000 and 1000 to 10,000 ppm range. Mark these duplicate samples and the original samples so that the lab realizes they are duplicates of each other.

- Sample from the hexane standard if there is plenty of gas remaining for a performance standard. Mark the samples as "PA."

Water Sampling

- Calibrate the Hydrolab using the pH buffers, electrical conductivity standards, redox potential standards, and the barometric pressure. Call base weather (x3271) to get the daily reading for uncorrected barometric pressure in mm Hg. Record the calibration in the TS logbook #3. The manual has details on calibrating the Hydrolab. Also, the previous calibrations are recorded in the lab calibration logbook.

- Prior to sampling the groundwater wells, get water level measurements with the oil-water interface meter. This meter will also measure the amount of free product in each well. Historically, wells W-1, W-4, W-3, and W-8 have had free product in them.

- Calibrate the downhole dissolved oxygen (DO) meter according to procedures outlined in the instruction manual. Take DO and temperature (using the DO meter) measurements every 5 ft. in the wells that do not contain free product (oil coats the membrane and is not good for the probe). For wells that contain free product, take downhole temperature measurements with the downhole thermocouple and the digital thermometer at five foot intervals. DO readings for these wells will be taken using the Hydrolab flow cell. Decontaminate the probe and thermocouple between wells.

- Purge each well a maximum of 3 times the wetted volume [8-11 gal. for all wells except W-1 (50 gal.)]. While purging, take measurements with the Hydrolab every 2-3 gal. Once the DO and temperature measurements have stabilized, purging can be discontinued (typically 4 to 6 gal.). Previously, we have used the Waterra tubing and foot valves to pump groundwater from the well through the Hydrolab. You may have to get additional drums from the 11th CEOS for the purge water. For W-1 (the 6 in. monitoring well), you can use the utility pump to help purge the wells. There are hose fittings on the inlet and outlet of the pump. Every 10 gal., you will probably have to disconnect the pump and connect the Hydrolab to the Waterra tubing to get readings. There are some hose fittings in the box with Brian that may allow you to sample through the Hydrolab and then through the pump so that you won't have to disconnect the pump each time you sample.

- After the well has been purged, place the foot valve 5 ft. below the water table and collect approximately 200-250 mL in a 500-mL clear glass bottle. This sample will be analyzed with the TPH-IR (total petroleum hydrocarbons) field analyzer. Place the samples in the refrigerator until you are ready to analyze them.

Water Analyses

- The TPH analyzer is fairly easy to use for water samples. Turn on the TPH analyzer in the morning. It should warm up at least a couple of hours before using. The work should be performed near the hood as much as possible to prevent exposure to organic vapors. Also, do not place water in the cuvettes or volumetric flasks. Clean them with freon.

- Prepare the cuvettes for the standards and a zero by rinsing them three times with Freon 113. Dispense approximately 5 mL of freon into the cartridge. Get one of the filters from the Ziploc® bag and place it on the cartridge first, then put the filter with the cartridge on last. Pressurize the cartridge with the syringe. Discard the first mL into a freon waste jar. Any freon waste should ultimately be discarded in the solvent can by the hood. Fill the cuvette with the filtered freon until the cuvette is at least 3/4 full. This becomes your zero blank. Set the instrument with the blank to zero. Record the dial readings before you change them. Then record the dial readings after the instrument is rezeroed. Give the instrument plenty of time before you adjust the zero. I usually gave it 20-25 minutes.

- The standards are already prepared (in freon). There are two concentrations of standards in the refrigerator in VOA vials. Open one vial of each concentration and pipette a few mLs into the remaining cuvettes. The cuvette caps are marked with numbers, to you can record what each cuvette contains. Check the measurement by the analyzer using the standards. The readings should be within 25 percent. There is no adjustment for the span if these are out of specification. If they are really off, I would reset to zero and make sure you give the instrument plenty of time to reach a steady value.

- Since you need to check the calibration every 4-5 samples and at the end of the day, you will need to keep the zero blank cuvette and one of the standards (the higher concentration) during the duration of the analyses. I would get one of the small coolers and fill it with ice and place the cuvettes in there when you are not using them to prevent loss of volatile components.

- Measure the volume of sample collected in a graduated cylinder and return to the sample bottle. Add 20 mL (approximately 1:10 dilution) of Freon 113 from the dispenser to the sample bottle. Shake vigorously for 5 minutes. Let the sample settle for 1-2 minutes. It is expedient to wash the graduated cylinder while the sample is settling. After washing, rinse with DI water. The water at the hangar is nasty! After the sample has settled, prepare the cartridge for a sample by placing the water filter (from the Ziploc® bag) and then the second filter on the cartridge. Using the 10-mL pipette, transfer approximately 8-9 mL of the freon layer (bottom of the sample bottle) to the cartridge. Rinse the cuvette with freon to prepare it for the sample. I usually placed it in the hood to allow the residual freon to evaporate from the cuvette. Pressurize the cartridge and discard the first 1-2 mL of sample into the waste jar. Then transfer the filtered sample to the cuvette and record the measurement after the reading stabilizes. The concentration in mg/L is calculated from the following equation:

Freon Volume (mL) * Reading (mg/L) / Sample Volume (mL)

If the reading is greater than 500 on the meter, then a dilution has to be made. Transfer 1 mL from the cuvette to a 10-mL freon-rinsed volumetric flask using a 1-mL pipette. Add filtered (using both filters) freon to the mark on the volumetric flask. The actual concentration is 10 times the calculated concentration from above with a 10:1 dilution. Sometimes a 100:1 dilution is required. This requires transferring 1 mL of the 10:1 diluted sample and performing a 10:1 dilution on it. This procedure is also discussed in the GAC manual. Dispose of any solid waste (filters, cartridges, gloves) into a Ziploc bag and transfer these and the empty sample bottles to one of the solid waste drums at the site after you are done with the analyses. Transfer the remaining freon layer in the sample bottle to the freon waste jar. The groundwater can be returned to the purge water drums.

Soil Sampling

- Sample both boreholes per location (12 locations total) and one duplicate using the Art's system and the Bosch hammer. One set of samples plus the duplicate will go to SASI, and the other set should go to Radian at Mopac. The sleeves and end caps should be in the hangar. The sample labels have been preprinted (Brian has them).

- After the soil samples have been collected, add bentonite pellets and then water to the bore holes.

Air Permeability Test

1, Shut off both SVE units.
2. Wait one hour.
3. Obtain the Air Permeability Test Log form.
4. Find the 2 in., 5 in., and 10 in. H_2O vacuum gauges.
5. Restart the west SVE.
6. Immediately start taking vacuum readings at vapor points V-1, V-2, V-6, V-7, V-8, and V-10.
7. Take readings as often as possible for the first 30 minutes and every 15 minutes afterwards until 2 hours has elapsed. Then take readings once per hour until all readings have stabilized (it is possible that the readings will be stable after two hours). Also, periodically take readings from V-20 and V-14 on the east side.
8. Shut off the west SVE and wait one hour.
9. Start the east SVE and proceed as above. Monitor points V-7 on the west side in addition to V-12, V-13, V-14, V-15, V-16, and V-20.
10. Restart the west SVE when the test is finished.

Table C-2
Analytical Results for the East Unit Soils

Location	Analyte	Units	S0	S1	S2	S3	S4	S5	S6
B-7	TPH-GC	ppm	39.44	6.06	754.6	<1	<1	<1	<1
B-7	DRO	ppm	18.92		445		<1		<1
B-7	GRO	ppm	4.7		61.89		22.9		<1
B-7	Total BTEX	ppm	0		2.57		<0.5		<0.5
B-7	Temperature	C°			3.6			3.6	2.6
B-7	NO3-N	ppm	<1						<1
B-7	NH4-N	ppm	1.3						<1
B-7	PO4-P	ppm	30						13
B-7	Heterotrophic Bacteria	CFU/g			3.0E+06		8.5E+06		3.0E+07
B-7	Hydrocarbon Utilizing Bacteria	CFU/g			<1.0E+02		7.6E+05		5.1E+03
B-7	TOC	%	0.02						0.6
B-7	pH	pH							8.3
B-7	TKN	ppm							280
B-7	TRPH-IR	ppm	0						
B-7 FD	TPH-GC	ppm	47.27						
B-7 FD	DRO	ppm	21.95						
B-7 FD	GRO	ppm	44.06						
B-7 FD	Total BTEX	ppm	4.39						
B-7 LD	NO3-N	ppm							<1
B-7 LD	NH4-N	ppm							<1
B-7 LD	PO4-P	ppm							12.9

Table C-2
(Continued)

Location	Analyte	Units	S0	S1	S2	S3	S4	S5	S6
B-7 FD	Heterotrophic Bacteria	CFU/g	2.2E+07						
B-7 FD	Hydrocarbon Utilizing Bacteria	CFU/g	1.1E+05						
B-7 LD	TOC	%							0.5
B-7 LD	pH	pH							8.3
B-7 LD	TKN	ppm							315
B-8	TPH-GC	ppm	19.73	5.82	<1	2.03	<1	<1	<1
B-8	DRO	ppm	9.2		<1		<1		<1
B-8	GRO	ppm	29.53		4.61		<1		<1
B-8	Total BTEX	ppm	2.65		<0.5		<0.5		<0.5
B-8	Temperature	C°			6.7			18	3.9
B-8	NO3-N	ppm	<1						5.5
B-8	NH4-N	ppm	2.7						4.0
B-8	PO4-P	ppm	9.3						13.7
B-8	Heterotrophic Bacteria	CFU/g					7.3E+06		1.4E+07
B-8	Hydrocarbon Utilizing Bacteria	CFU/g			5.0E+03		3.8E+05		4.7E+05
B-8	TOC	%	0.29						0.5
B-8	pH	pH							9.4
B-8	TKN	ppm							246
B-8	TRPH-IR	ppm	0						
B-8 FD	TPH-GC	ppm	3.59						
B-8 FD	DRO	ppm	1.58						

Table C-2
(Continued)

Location	Analyte	Units	S0	S1	S2	S3	S4	S5	S6
B-8 FD	GRO	ppm	130.5						
B-8 FD	Total BTEX	ppm	4.05						
B-8 FD	Heterotrphic Bacteria	CFU/g	8.0E+06						
B-8 FD	Hydrocarbon Utilizing Bacteria	CFU/g	5.3E+06						
B-9	TPH-GC	ppm	0.75	6.47	<1	<1	<1	<1	<1
B-9	DRO	ppm	<0.5		<1		<1		<1
B-9	GRO	ppm	5.72		<1		6.28		<1
B-9	Total BTEX	ppm	0		1.09		<0.5		<0.5
B-9	Temperature	C°			4.3			5.9	8.5
B-9	NO3-N	ppm	<1						<1
B-9	NH4-N	ppm	1.7						<1
B-9	PO4-P	ppm	11.5						2.59
B-9	Heterotrophic Bacteria	CFU/g			1.4E+06		1.8E+06		1.6E+07
B-9	Hydrocarbon Utilizing Bacteria	CFU/g			6.4E+03		3.6E+06		1.3E+06
B-9	TOC	%	0.34						0.2
B-9	pH	pH							8.3
B-9	TKN	ppm							92
B-9	TRPH-IR	ppm	0						
B-9 FD	TPH-GC	ppm	0.89						
B-9 FD	DRO	ppm	<0.5						
B-9 FD	GRO	ppm	95.72						

Table C-2
(Continued)

Location	Analyte	Units	S0	S1	S2	S3	S4	S5	S6
B-9 FD	Total BTEX	ppm	1.3						
B-9 FD	Heterotrophic Bacteria	CFU/g	8.7E+05						
B-9 FD	Hydrocarbon Utilizing Bacteria	CFU/g	1.9E+05						
B-9 LD	TPH-GC	ppm					<1		
B-9 LD	DRO	ppm					<1		
B-9 LD	GRO	ppm					4.72		
B-9 LD	Total BTEX	ppm					<0.5		
B-9 LD	NO3-N	ppm	<1						
B-9 LD	NH4-N	ppm	<1						
B-9 LD	PO4-P	ppm	11.9						
B-9 LD	TOC	%	0.35						
B-10	TPH-GC	ppm	0.89	6.53	3.95	3.41	<1	<1	<1
B-10	DRO	ppm	<0.5		1.74		<1		<1
B-10	GRO	ppm	7.13		<1		3.37		<1
B-10	Total BTEX	ppm	0.79		<0.5		<0.5		<0.5
B-10	Temperature	C°			6.1			5.6	5.3
B-10	NO3-N	ppm	<1						<1
B-10	NH4-N	ppm	1.4						<1
B-10	PO4-P	ppm	25						17.2
B-10	Heterotrophic Bacteria	CFU/g			7.2E+06		5.4E+06		2.1E+07
B-10	Hydrocarbon Utilizing Bacteria	CFU/g			2.1E+05		6.7E+05	4.9E+05	

Table C-2
(Continued)

Location	Analyte	Units	S0	S1	S2	S3	S4	S5	S6
B-10	TOC	%	0.2						0.3
B-10	pH	pH							9.2
B-10	TKN	ppm							88
B-10	TRPH-IR	ppm	0						
B-10 FD	TPH-GC	ppm	0.89						
B-10 FD	DRO	ppm	<0.5						
B-10 FD	GRO	ppm	4.51						
B-10 FD	Total BTEX	ppm	0						
B-10 FD	Heterotrophic Bacteria	CFU/g	4.5E+06						
B-10 FD	Hydrocarbon Utilizing Bacteria	CFU/g	3.9E+03						
B-11	TPH-GC	ppm	7.82	28.44	4.13	6.1	<1	<1	<1
B-11	DRO	ppm	3.45		1.81		<1		<1
B-11	GRO	ppm	3.95		<1		12.66		<1
B-11	Total BTEX	ppm	0		2.04		<0.5		<0.5
B-11	Temperature	C°			5.5			6.8	
B-11	NO3-N	ppm	<1						<1
B-11	NH4-N	ppm	1.2						2.7
B-11	PO4-P	ppm	5.0						15.2
B-11	Heterotrophic Bacteria	CFU/g			2.4E+06		1.6E+07		3.2E+07
B-11	Hydrocarbon Utilizing Bacteria	CFU/g			<1.0E+02		3.4E+05		1.5E+06
B-11	TOC	%	0.85						1.2

Table C-2
(Continued)

Location	Analyte	Units	S0	S1	S2	S3	S4	S5	S6
B-11	pH	pH							8.6
B-11	TKN	ppm							643
B-11	TRPH-IR	ppm	0						
B-11 FD	TPH-GC	ppm	1.73						
B-11 FD	DRO	ppm	0.76						
B-11 FD	GRO	ppm	79.7						
B-11 FD	Total BTEX	ppm	2.98						
B-11 LD	NO3-N	ppm	<1						
B-11 LD	NH4-N	ppm	1.1						
B-11 LD	PO4-P	ppm	4.7						
B-11 FD	Heterotrophic Bacteria	CFU/g	4.9E+07						
B-11 FD	Hydrocarbon Utilizing Bacteria	CFU/g	1.1E+07						
B-11 LD	TOC	%	0.86						
B-12	TPH-GC	ppm	4.79	5.85	<1	2.53	<1	<1	<1
B-12	DRO	ppm	2.36		<1		<1		<1
B-12	GRO	ppm	34.88		3.71		17.28		<1
B-12	Total BTEX	ppm	3.04		<0.5		<0.5		<0.5
B-12	Temperature	C°			5.8			3.8	
B-12	NO3-N	ppm	<1						<1
B-12	NH4-N	ppm	2.8						<1
B-12	PO4-P	ppm	6.6						17.7

Table C-2
(Continued)

Location	Analyte	Units	S0	S1	S2	S3	S4	S5	S6
B-12	Heterotrophic Bacteria	CFU/g			1.5E+07		5.6E+07		1.4E+05
B-12	Hydrocarbon Utilizing Bacteria	CFU/g			3.8E+06		6.7E+06		5.8E+03
B-12	TOC	%	0.75						0.6
B-12	pH	pH							9
B-12	TKN	ppm							224
B-12	TRPH-IR	ppm	21						
B-12 FD	TPH-GC	ppm	3.52						
B-12 FD	DRO	ppm	1.55						
B-12 FD	GRO	ppm	16.22						
B-12 FD	Total BTEX	ppm	1.12						
B-12 FD	Heterotrophic Bacteria	CFU/g	1.0E+07						
B-12 FD	Hydrocarbon Utilizing Bacteria	CFU/g	2.3E+05						

S0 - Samples collected 7/29/93
S1 - Samples collected 9/2/93
S2 - Samples collected 10/3/93 - 10/5/93
S3 - Samples collected 11/1/93 - 11/2/93
S4 - Samples collected 12/6/93 - 12/10/93
S5 - Samples collected 1/6/94 - 1/7/94
S6 - Samples collected 2/5/94 - 2/6/94

FD = Field duplicate
LD = Lab duplicate
FD/LD = Lab duplicate of field duplicate

Table C-3
Analytical Results for the West Unit Soils

Location	Analyte	Units	S0	S1	S2	S3	S4	S5	S6
B-1	TPH-GC	ppm	1374	1492	294.8	836.7	478.9	396.1	261.70
B-1	DRO	ppm	984.5		246.3		563.4		245.4
B-1	GRO	ppm	4642		123.3		293.9		94.1
B-1	Total BTEX	ppm	233.42		2		7.55		< 0.5
B-1	Temperature	C°			19.2		25.1	45.1	21.7
B-1	NO3-N	ppm	< 1						< 1
B-1	NH4-N	ppm	< 1						< 1
B-1	PO4-P	ppm	10.8						17.5
B-1	Heterotrophic Bacteria	CFU/g			1.9E+07		1.4E+08		1.7E+07
B-1	Hydrocarbon Utilizing Bacteria	CFU/g			< 1.0E+02		6.4E+06		7.9E+05
B-1	TOC	%	0.28						0.4
B-1	pH	pH							8.7
B-1	TKN	ppm							212
B-1	TRPH-IR	ppm	1186						
B-1 FD	TPH-GC	ppm	1033						
B-1 FD	DRO	ppm	940.6						
B-1 FD	GRO	ppm	1828						
B-1 FD	Total BTEX	ppm	124.04						
B-1 FD	Heterotrophic Bacteria	CFU/g	6.9E+06						
B-1 FD	Hydrocarbon Utilizing Bacteria	CFU/g	3.3E+06						
B-1 LD	TPH-GC	ppm		1423		932.9			330.50

Table C-3
(Continued)

Location	Analyte	Units	S0	S1	S2	S3	S4	S5	S6
B-1 LD	DRO	ppm							315.6
B-1 LD	GRO	ppm	2687						112.3
B-1 LD	Total BTEX	ppm	210.72						< 0.5
B-2	TPH-GC	ppm	0.89	6.41	15.49	<1	<1	<1	22.97
B-2	DRO	ppm	< 0.5		7.43		< 1		6.25
B-2	GRO	ppm	6.68		14.62		16.21		< 1
B-2	Total BTEX	ppm	0		< 0.5		< 0.5		< 0.5
B-2	Temperature	C°			16.4		18.3	18.6	
B-2	NO3-N	ppm	< 1						6.2
B-2	NH4-N	ppm	3.2						< 1
B-2	PO4-P	ppm	10.6						13.1
B-2	Heterotrphic Bacteria	CFU/g			1.1E+07		6.5E+07		8.2E+06
B-2	Hydrocarbon Utilizing Bacteria	CFU/g			< 1.0E+02		3.4E+06		< 1.0E+02
B-2	TOC	%	0.25						0.6
B-2	pH	pH							8.6
B-2	TKN	ppm							648
B-2	TRPH-IR	ppm	401						
B-2 FD	TPH-GC	ppm	3.77						28.73
B-2 FD	DRO	ppm	1.73						4.09
B-2 FD	GRO	ppm	2.46						<1
B-2 FD	Total BTEX	ppm	0						< 0.5
B-2 FD	NO3-N	ppm							7.1

Table C-3
(Continued)

Location	Analyte	Units	S0	S1	S2	S3	S4	S5	S6
B-2 FD	NH4-N	ppm							< 1
B-2 FD	PO4-P	ppm							12.7
B-2 FD	Heterotrophic Bacteria	CFU/g	5.6E+07						
B-2 FD	Hydrocarbon Utilizing Bacteria	CFU/g	1.1E+07						
B-2 FD	TOC	%							0.5
B-2 FD	pH	pH							8.1
B-2 FD	TKN	ppm							376
B-3	TPH-GC	ppm	11.05	6.85	<1	<1	<1	23.77	<1
B-3	DRO	ppm	6.71		< 1		< 1		< 1
B-3	GRO	ppm	5.23		1.38		20.99		< 1
B-3	Total BTEX	ppm	0.54		< 0.5		< 0.5		< 0.5
B-3	Temperature	C°			10.8			17.6	11.5
B-3	NO3-N	ppm	< 1						2
B-3	NH4-N	ppm	3.6						2.3
B-3	PO4-P	ppm	26.9						30.2
B-3	Heterotrophic Bacteria	CFU/g			2.5E+07		3.7E+07		2.9E+07
B-3	Hydrocarbon Utilizing Bacteria	CFU/g			2.1E+06		3.3E+06		7.3E+05
B-3	TOC	%	0.11						0.2
B-3	pH	pH							8.5
B-3	TKN	pm							60
B-3	TRPH-IR	ppm	8						

Table C-3
(Continued)

Location	Analyte	Units	S0	S1	S2	S3	S4	S5	S6
B-3 FD	TPH-GC	ppm	8.73		2.39				
B-3 FD	DRO	ppm	4.05		< 1				
B-3 FD	GRO	ppm	4.23		8.42				
B-3 FD	Total BTEX	ppm	0		< 0.5				
B-3 FD	Heterotrophic Bacteria	CFU/g	4.8E+07						
B-3 FD	Hydrocarbon Utilizing Bacteria	CFU/g	1.3E+07						
B-4	TPH-GC	ppm	3.1	5.78	2.34	<1	<1	1.00	<1
B-4	DRO	ppm	1.37		< 1		< 1		< 1
B-4	GRO	ppm	32.39		22.63		18.85		< 1
B-4	Total BTEX	ppm	4.97		2.88		< 0.5		< 0.5
B-4	Temperature	C°						21.9	7.3
B-4	NO3-N	ppm	< 1						7.4
B-4	NH4-N	ppm	10						2.5
B-4	PO4-P	ppm	8.9						21.5
B-4	Heterotrophic Bacteria	CFU/g			1.0E+07		2.6E+07		3.0E+07
B-4	Hydrocarbon Utilizing Bacteria	CFU/g			4.7E+05		6.8E+05		1.2E+06
B-4	TOC	%	0.73						0.6
B-4	pH	pH							8.3
B-4	TKN	ppm							196
B-4	TRPH-IR	ppm	10						
B-4 FD	TPH-GC	ppm	7.15						

Table C-3
(Continued)

Location	Analyte	Units	S0	S1	S2	S3	S4	S5	S6
B-4 FD	DRO	ppm	3.16						
B-4 FD	GRO	ppm	51.58						
B-4 FD	Total BTEX	ppm	6.72						
B-4 FD	Heterotrophic Bacteria	CFU/g	4.5E+06						
B-4 FD	Hydrocarbon Utilizing Bacteria	CFU/g	8.0E+04						
B-5	TPH-GC	ppm	8.67	5.68	<1	<1	<1		
B-5	DRO	ppm	4.16		< 1		< 1		
B-5	GRO	ppm	7.62		1.64		2.55		
B-5	Total BTEX	ppm	0		< 0.5		< 0.5		
B-5	NO3-N	ppm	< 1						
B-5	NH4-N	ppm	6.5						
B-5	PO4-P	ppm	6.5						
B-5	Heterotrophic Bacteria	CFU/g			1.7E+06		7.5E+07		
B-5	Hydrocarbon Utilizing Bacteria	CFU/g			9.8E+03		5.4E+06		
B-5	TOC	%	0.46						
B-5	TRPH-IR	ppm	14						
B-5 FD	TPH-GC	ppm	4.49			<1			
B-5 FD	DRO	ppm	1.98						
B-5 FD	GRO	ppm	11.5						
B-5 FD	Total BTEX	ppm	2.04						
B-5 FD	Heterotrophic Bacteria	CFU/g	3.0E+07						

Table C-3
(Continued)

Location	Analyte	Units	S0	S1	S2	S3	S4	S5	S6
B-5 FD	Hydrocarbon Utilizing Bacteria	CFU/g	7.4E+07						
B-6	TPH-GC	ppm	5444	7360	13886	3455	1254	1597	1536
B-6	DRO	ppm	4556		6282		2023		1490
B-6	GRO	ppm	13451		10812		119.6		595
B-6	Total BTEX	ppm	1092.68		305.91		2.27		< 0.5
B-6	Temperature	C°			36.2		41.5	43.8	39.9
B-6	NO3-N	ppm	< 1						< 1
B-6	NH4-N	ppm	12.9						< 1
B-6	PO4-P	ppm	7.6						17.6
B-6	Heterotrophic Bacteria	CFU/g			7.6E+07		8.7E+07		3.6E+08
B-6	Hydrocarbon Utilizing Bacteria	CFU/g			4.0E+06		2.9E+07		9.9E+07
B-6	TOC	%	1.28						0.8
B-6	pH	pH							8.2
B-6	TKN	ppm							410
B-6	TRPH-IR	ppm	19053						
B-6 FD	TPH-GC	ppm	4373					2581	
B-6 FD	DRO	ppm	3470						
B-6 FD	GRO	ppm	21066						
B-6 FD	Total BTEX	ppm	1683.2						
B-6 FD	Heterotrophic Bacteria	CFU/g	6.4E+07						

Table C-3
(Continued)

Location	Analyte	Units	S0	S1	S2	S3	S4	S5	S6
B-6 FD	Hydrocarbon Utilizing Bacteria	CFU/g	< 1.0E+02						
B-6 FD	TOC	%							
B-6 FD	pH	pH							
B-6 FD	TKN	ppm							
B-6 FD	TRPH-IR	ppm							
B-6 LD	TPH-GC	ppm		7898	14352	3802	1358	1532	
B-6 LD	DRO	ppm			6450		2204		
B-6 LD	GRO	ppm	9556		10796		130.8		626.5
B-6 LD	Total BTEX	ppm	664.39		304.91				< 0.5
B-6 FD/LD	TPH-GC	ppm						2566	

S0 - Samples collected 7/29/93
S1 - Samples collected 9/2/93
S2 - Samples collected 10/3/93 - 10/5/93
S3 - Samples collected 11/1/93 - 11/2/93
S4 - Samples collected 12/6/93 - 12/10/93
S5 - Samples collected 1/6/94 - 1/7/94
S6 - Samples collected 2/5/94 - 2/6/94

FD = Field duplicate
LD = Lab duplicate
FD/LD = Lab duplicate of field duplicate

Table C-4
Analytical Results for the East Unit Groundwater

Location	Analyte	Units	W0	W1	W2	W3	W4	W5	W6
W-5	Dissolved Oxygen	mg/L	0.52	0.66	0.56	0.62	0.62	0.62	0.32
W-5	Temperature	°C	2.72	2.00	3.28	1.91	1.56	0.12	2.47
W-5	Product Thickness	ft.	0	0	0	0	0	0[a]	0
W-5	TPH-GC	ppm	7.34						37.13
W-5	TRPH-IR	ppm	60.10	46.80	54.30	20.00	13.20	20.00	
W-5	NO3-N	ppm	<1						<1
W-5	NH4-N	ppm	<1						<1
W-5	PO4-P	ppm	<1						<1
W-5	Heterotrophic Bacteria	CFU/g	<100				3.9E+03		3.4E+05
W-5	Hydrocarbon Utilizing Bacteria	CFU/g	<100				<100		<100
W-6	Dissolved Oxygen	mg/L	0.30	0.89	0.26	0.93			4.04
W-6	Temperature	°C	3.41	3.46	3.55	2.64	1.30	0.22	2.51
W-6	Product Thickness	ft.	0	0	0	0.01	0	0[a]	0
W-6	TPH-GC	ppm	0.13						30.46
W-6	TRPH-IR	ppm	48.50	39.40	69.60	22.20	11.50	18.60	
W-6	NO3-N	ppm	<1						<1
W-6	NH4-N	ppm	<1						<1
W-6	PO4-P	ppm	<1						<1
W-6	Heterotrophic Bacteria	CFU/g	3.4E+03				3.4E+03		4.4E+06
W-6	Hydrocarbon Utilizing Bacteria	CFU/g	<100				<100		<100
W-7	Dissolved Oxygen	mg/L	0.29	0.36	0.07	0.26			3.8
W-7	Temperature	°C	2.79	2.45	2.83	1.81	0.87	0.12	2.02
W-7	Product Thickness	ft.		0	0	0.01	0	0[a]	0
W-7	TPH-GC	ppm	7.17						23.71
W-7 FD	TPH-GC	ppm							21.39
W-7	TRPH-IR	ppm	36.90	47.90	70.20	13.80	7.90	8.5	
W-7 LD	TRPH-IR	ppm				12.20			

Table C-4
(Continued)

Location	Analyte	Units	W0	W1	W2	W3	W4	W5	W6
W-7	NO3-N	ppm	<1						<1
W-7 FD	NO3-N	ppm							<1
W-7	NH4-N	ppm	<1						<1
W-7 FD	NH4-N	ppm							<1
W-7	PO4-P	ppm	<1						<1
W-7 FD	PO4-P	ppm							<1
W-7	Heterotrophic Bacteria	CFU/g	1.5E+06				5.0E+04		3.2E+05
W-7	Hydrocarbon Utilizing Bacteria	CFU/g	3.4E+03				<100		2.6E+03
W-8	Dissolved Oxygen	mg/L	0.45	0.62	0.76	2.70			0.50
W-8	Temperature	°C	1.37	1.22	1.79	0.05	1.15	-0.07	0.91
W-8	Product Thickness	ft.	1.36	1.8	0.46	1.2	0.5	0[a]	0
W-8	TPH-GC	ppm	18.97						33.22
W-8	TRPH-IR	ppm	1164.00	74.50	128.40	373.60	27.00	130.00	
W-8	NO3-N	ppm							<1
W-8	NH4-N	ppm							<1
W-8	PO4-P	ppm							<1
W-8	Heterotrophic Bacteria	CFU/g	1.1E+03				4.9E+04		4.8E+05
W-8	Hydrocarbon Utilizing Bacteria	CFU/g	<100				1.9E+04		<100

W0 - Samples collected 7/31/93
W1 - Samples collected 9/3/93 - 9/4/93
W2 - Samples collected 10/1/93
W3 - Samples collected 11/4/93
W4 - Samples collected 12/9/93 - 12/10/93
W5 - Samples collected 1/9/94
W6 - Samples collected 2/6/94 - 2/7/94

[a] Free product lens observed during sampling.

LD = Lab duplicate

KO-E = Knockout drum in the East Unit

Table C-5
Analytical Results for the West Unit Groundwater

Location	Analyte	Units	W0	W1	W2	W3	W4	W5	W6
W-1	Dissolved Oxygen	mg/L	0.53	0.77	0.88	2.13			0.83
W-1	Temperature	°C	4.47	3.35	3.61	3.33	0.03	1.42	3.21
W-1	Product Thickness	ft.	0	1.25	0	0.29	0.6	0.04	0.04
W-1	TPH-GC	ppm	301.50						64.05
W-1	TRPH-IR	ppm	2231.00	244.40	149.80	461.00	1820[a]	292	
W-1	NO3-N	ppm	<1						<1
W-1	NH4-N	ppm	<1						1.4
W-1	PO4-P	ppm	<1						<1
W-1	Heterotrophic Bacteria	CFU/g	1.9E+06				1.2E+06		3.7E+06
W-1	Hydrocarbon Utilizing Bacteria	CFU/g	<100				<100		9.6E+05
W-2	Dissolved Oxygen	mg/L	0.37	0.60	0.47	0.47			0.57
W-2	Temperature	°C	2.47	1.98	5.59	3.73	2.61	2.86	6.94
W-2	Product Thickness	ft.	0	0	0	1.85	2.41	2.07	2.12
W-2	TPH-GC	ppm	20.67						40.75
W-2 LD	TPH-GC	ppm	18.94						
W-2	TRPH-IR	ppm	184.30	67.90	108.60	30.80	24600[a]	806[a]	
W-2	NO3-N	ppm	<1						<1
W-2	NH4-N	ppm	<1						<1
W-2	PO4-P	ppm	<1						<1
W-2	Heterotrophic Bacteria	CFU/g	800				4.4E+05		6.5E+05
W-2	Hydrocarbon Utilizing Bacteria	CFU/g	<100				2.7E+03		1.3E+03
W-3	Dissolved Oxygen	mg/L	0.39	0.25	0.34	0.37			0.77
W-3	Temperature	°C	1.95	2.17	4.17	3.00	2.62	3.76	10.05
W-3	Product Thickness	ft.	0	1.7	0.85	2.12	2.34	1.96	2.13
W-3	TPH-GC	ppm	4.44						10.36

Table C-5
(Continued)

Location	Analyte	Units	W0	W1	W2	W3	W4	W5	W6
W-3	TRPH-IR	ppm	48.50	97.00	122.60	55.40	15200[a]	87.70	
W-3 LD	TRPH-IR	ppm						86.5	
W-3	NO3-N	ppm	<1						<1
W-3	NH4-N	ppm	<1						<1
W-3	PO4-P	ppm	<1						<1
W-3	Heterotrophic Bacteria	CFU/g	<100				<100		1.3E+04
W-3	Hydrocarbon Utilizing Bacteria	CFU/g	<100				<100		<100
W-4	Dissolved Oxygen	mg/L	0.30	0.41	0.34	0.41			0.56
W-4	Temperature	°C	0.84	0.75	1.33	0.79	0.19	0.20	1.20
W-4	Product Thickness	ft.	0	1.45	0.87	1.98	3.96	1.65	2.19
W-4	TPH-GC	ppm	36.72						199.60
W-4	TRPH-IR	ppm	242.50	194.00	161.20	64.6	10000[a]	380[b]	
W-4 FD	TRPH-IR	ppm						165[b]	
W-4 FD/LD	TRPH-IR	ppm						169[b]	
W-4	NO3-N	ppm	<1						<1
W-4	NH4-N	ppm	<1						1.1
W-4	PO4-P	ppm	<1						<1
W-4	Heterotrophic Bacteria	CFU/g	1.0E+05				<100		3.0E+03
W-4	Hydrocarbon Utilizing Bacteria	CFU/g	<100				<100		<100

W0 - Samples collected 7/31/93
W1 - Samples collected 9/3/93 - 9/4/93
W2 - Samples collected 10/1/93
W3 - Samples collected 11/4/93
W4 - Samples collected 12/9/93
W5 - Samples collected 1/9/94
W6 - Samples collected 2/6/94 - 2/7/94

FD = Field duplicate
LD = Lab duplicate
FD/LD = Lab duplicate of Field duplicate

[a] Free phase hydrocarbons observed in groundwater samples.

[b] Possible free product contamination.

Table C-6
Total Non-Methane Hydrocarbon and Total BTEX Laboratory Results for the SVE Exhaust Gas

Sample Type	Analyte	Units	G0	G1	G2	G3[a]	G4	G5	G6	G7	G8
West Unit											
Primary sample	TNMHC	ppm	29500	20100	21500	18500	13633	22900	21400	20300	19400
Lab dup of primary sample	TNMHC	ppm	29400	20400	21400		13500		20200		19400
Field duplicate	TNMHC	ppm	28300	16800	20300	19800	13833	14900	19600		18500
Lab dup of field dup	TNMHC	ppm	28500	17900	20400		13900		19600		18600
Primary sample	Total BTEX	ppm	1550.2	1314.6	1303.6	1355.9	949.3	1580.3	1349.0	1339.4	976.0
Lab dup of primary sample	Total BTEX	ppm	1536.2	1338.0	1289.2		954.0		1273.0		980.0
Field duplicate	Total BTEX	ppm	1517.8	1046.7	1256.5	1439.7	975.4	1028.9	1228.0		952.0
Lab dup of field dup	Total BTEX	ppm	1546.1	1149.2	1281.8		975.3		1222.0		956.0
East Unit											
Primary sample	TNMHC	ppm	3310.0	1090.0	620.0	1510.0	181.7	6540.0	5430.0	1810.0	4640.0
Lab dup of primary sample	TNMHC	ppm	4270.0	1110.0			181.7	6530.0			
Field duplicate	TNMHC	ppm	3760.0	1190.0	875.0	2240.0	173.3	6480.0			
Lab dup of field dup	TNMHC	ppm	4850.0	1090.0		2240.0	173.3	6350.0			
Primary sample	Total BTEX	ppm	59.7	95.6	48.2	105.9	12.4	492.1	433.0	138.2	330.0
Lab dup of primary sample	Total BTEX	ppm	51.2	94.0			12.3	491.0			
Field duplicate	Total BTEX	ppm	67.3	94.0	68.7	126.1	11.4	485.0			
Lab dup of field dup	Total BTEX	ppm	60.8	85.4		125.9	11.4	475.4			

G0 - Samples collected 7/30/93 - 8/3/93
G1 - Samples collected 8/6/93 - 8/9/93
G2 - Samples collected 8/19/93 - 8/23/93
G3 - Samples collected 9/1/93 - 9/3/93
G4 - Samples collected 10/2/93 - 10/3/93
G5 - Samples collected 11/3/93
G6 - Samples collected 12/8/93
G7 - Samples collected 1/9/94
G8 - Samples collected 2/6/94 (East) and 2/10/94 (West)

[a] Field duplicates not taken on same day as primary samples.

Table C-7
Analytical Results for the Soil Gas Collected in the East Unit

Location	Analyte	Units	G0	G1	G2	G3	G4	G5	G6	G7	G8
V-11D	CO2	%			2.1	1.3	1.8		0.2	0.5	0.7
V-11D	O2	%			19.5	20.5	20.1		21.0	20.9	20.2
V-11D	TNMHC	ppm					350				53.3
V-11D	Total BTEX	ppm					71.5				1.02
V-11S	Temperature	°C				10.6					-0.1
V-12D	CO2	%			6.3	5	2.7	0.9	0.2	0.8	0.7
V-12D	O2	%			14.1	16.5	19.5	20.7	20.5	20.5	20.4
V-12D	TNMHC	ppm					617				132
V-12D	Total BTEX	ppm					125				3.40
V-12D LD	TNMHC	ppm					613				146
V-12D LD	Total BTEX	ppm					124				3.77
V-12D FD	TNMHC	ppm					480				
V-12D FD	Total BTEX	ppm					93.8				
V-12D FD/LD	TNMHC	ppm					475				
V-12D FD/LD	Total BTEX	ppm					92.8				
V-12S	CO2	%	15.5	0.7				0.6	0		
V-12S	O2	%	4	20.5				20.8	21.0		
V-12S	TNMHC	ppm	13.7								
V-12S	Total BTEX	ppm	0.132								
V-12S	Temperature	°C						0.9			-0.1
V-13D	CO2	%			4.1	5.5	2.6	2	0.9	0.4	0.8
V-13D	O2	%			16.2	16.5	19.2	20	20.5	20.9	19.8
V-13D	TNMHC	ppm					13400				1750
V-13D	Total BTEX	ppm					796				143
V-13S	CO2	%	16	.05	2	1.3	1.2	0.6	0.1	0.6	0.6
V-13S	O2	%	7	21	18.9	19	20.8	20.9	21.0	20.8	20.5
V-13S	TNMHC	ppm	167		0.294		29.2				0.27
V-13S	Total BTEX	ppm	4.802		0.0292		5.66				0.02
V-13S	Temperature	°C				13				0.2	0.1
V-14D	CO2	%			2.5	3.8	3	2.2	1.2	0.6	1.4
V-14D	O2	%			18.9	17.5	19	19.5	20.0	19.5	18.5
V-14D	TNMHC	ppm					8470				1480
V-14D	Total BTEX	ppm					501				44.9
V-14D LD	TNMHC	ppm					8470				1550
V-14D LD	Total BTEX	ppm					503				44.2
V-14D FD	TNMHC	ppm					8220				1490
V-14D FD	Total BTEX	ppm					485				42.9
V-14D FD/LD	TNMHC	ppm					8180				1500

Table C-7
(Continued)

Location	Analyte	Units	G0	G1	G2	G3	G4	G5	G6	G7	G8
V-14D FD/LD	Total BTEX	ppm					485				43.20
V-14S	CO2	%	2	3	1.2	0.8	0.8	0.6	0.2	0.5	
V-14S	O2	%	20	20	20.5	20.5	20.9	20.9	21.0	20.0	
V-14S	TNMHC	ppm	14.3		0.673		113			192	
V-14S	Total BTEX	ppm	0.2712		0.0159		26.0			22.8	
V-14S	Temperature	°C					1.0	0.0		0.4	-0.1
V-15D	CO2	%			2.1	1	0.8	0.35	0.2	0.4	0.7
V-15D	O2	%			19.9	21	20.6	20.9	21.0	20.2	20.5
V-15D	TNMHC	ppm					118				0.7
V-15D	Total BTEX	ppm					27.5				0.03
V-15S	CO2	%	9		0.4	0.5	0.3	0.35	0.0	0.4	0.2
V-15S	O2	%	13.5		21	21	20.9	20.9	21.0	20.4	20.8
V-15S	TNMHC	ppm					230				0.08
V-15S	Total BTEX	ppm					51.4				0.0
V-15S	Temperature	°C				13.6	4.2	0.6	1.0	1.3	-0.1
V-16D	CO2	%			6.1	5.5	4	1.5	0.8	0.6	0.9
V-16D	O2	%			17	18	18.5	20.5	21.0	20.5	20.1
V-16D	TNMHC	ppm					184				1.0
V-16D	Total BTEX	ppm					17.8				0.03
V-16S	CO2	%	13	1	0.4	0.6	0.5		0.1		
V-16S	O2	%	6	20.5	21	21	20.9		21.0		
V-16S	TNMHC	ppm					99.8				
V-16S	Total BTEX	ppm					22.7				
V-16S	Temperature	°C								1.3	-0.3
V-17D	CO2	%			3.5	1.5	1.0	0.4	0.1	0.4	0.6
V-17D	O2	%			18.5	20.5	20.5	20.9	21.0	20.5	20.7
V-17D	TNMHC	ppm					77.3				12.7
V-17D	Total BTEX	ppm					16.1				0.53
V-17S	Temperature	°C									-0.3
V-18D	CO2	%				9.5	0.3	0.8	0.3	1.4	0.8
V-18D	O2	%				11.5	20.9	20.7	21.0	20.0	20.0
V-18D	TNMHC	ppm									405
V-18D	Total BTEX	ppm									34.7
V-18S	CO2	%				0.3		0.3			
V-18S	O2	%				21		20.9			
V-18S	Temperature	°C				13.4	4.0		0.4	1.5	-0.3
V-19D	CO2	%			1.1	1.5	3.2	0.8	0.5	0.6	
V-19D	O2	%			19.9	19	18.5	20.9	20.5	20.2	
V-19D	TNMHC	ppm				13100	2270				
V-19D	Total BTEX	ppm				19.8	94.7				
V-19S	CO2	%	13.5	0.5	2.3	3.7	2.8		0.2		

Table C-7
(Continued)

Location	Analyte	Units	G0	G1	G2	G3	G4	G5	G6	G7	G8
V-19S	O2	%	4	21	17	17	20		20.0		
V-19S	TNMHC	ppm	8.25				58.2				
V-19S	Total BTEX	ppm	0.150				8.4				
V-19S	Temperature	°C	13.1			13	1.8				
V-20D	CO2	%			0.5	1.5	3	1.5	1.5	0.6	0.8
V-20D	O2	%			20.5	19.5	18.2	20.5	20.0	20.5	20.2
V-20D	TNMHC	ppm					156				605
V-20D	Total BTEX	ppm					16.5				9.1
V-20S	CO2	%	6	0.5	1	2.5	2		0.0		
V-20S	O2	%	14	20.5	18.5	19	20		20.0		
V-20S	TNMHC	ppm	90.8				119				
V-20S	Total BTEX	ppm	0.823				13.7				
V-20S	Temperature	°C					1.0			-0.5	-1.1

FD = Field duplicate
LD = Lab duplicate
FD/LD = Lab duplicate of Field duplicate

Table C-8
Analytical Results for the Soil Gas Collected in the West Unit

Location	Analyte	Units	G0	G1	G2	G3	G4	G5	G6	G7	G8
V-1D	CO2	%			3.2	1		0.8	0.2	0.5	1.6
V-1D	O2	%			19	20.5		20.1	20.0	20.9	18.2
V-1D	Temperature	°C	0.0	1.3	0.5	0.2	0.5	4.6	7.5	18.6	9.5
V-1D	TNMHC	ppm								705	673
V-1D	Total BTEX	ppm								16.4	5.92
V-1D LD	TNMHC	ppm									671
V-1D LD	Total BTEX	ppm									5.91
V-1S	CO2	%	7	0.5	2.2	5	2.6	1.9	0.5	0.6	2.0
V-1S	O2	%	16	20.5	17.5	2	17	19	19.0	20.0	13.4
V-1S	TNMHC	ppm	13600				12600				715
V-1S	Total BTEX	ppm	435.3				497.3				21.1
V-1S	Temperature	°C				16.2	7.4	9.1	8.3	24.6	14.8
V-2D	CO2	%			1	1	0.8		2.0		
V-2D	O2	%			21.2	20.5	20.9		18.0		
V-2D	TNMHC	ppm					8370				
V-2D	Total BTEX	ppm					447				
V-2D	Temperature	°C	0.6	1.3	1.4	0.2	0.3	5.0	6.6	16.1	10.3
V-2S	CO2	%	0.5	0.5	4	5	5.7	4.2	6.0	7.5	5.9
V-2S	O2	%	20.9	20.5	16	13.5	14.5	14	12.0	12.0	12.5
V-2S	TNMHC	ppm	15600				13700				6070
V-2S	Total BTEX	ppm	604.08				433				120
V-2S LD	TNMHC	ppm									6080
V-2S LD	Total BTEX	ppm									120
V-2S FD	TNMHC	ppm									6210
V-2S FD	Total BTEX	ppm									100
V-2S FD/LD	TNMHC	ppm									6190
V-2S FD/LD	Total BTEX	ppm									100
V-2S	Temperature	°C				17.2		14.1	10.8	33.6	24.7
V-3D	CO2	%			8	4	0.5	3.9	5.0	5.5	6.2
V-3D	O2	%			11	18	20.9	15	14.5	14.5	12.4
V-3D	TNMHC	ppm							16300		18400
V-3D	Total BTEX	ppm							629		623
V-3D	Temperature	°C	1.2	1.1	1.4	0.5	1.4	7.1	9.5	18.9	16.8
V-3S	CO2	%	0.5	0.5	9.5	6.5	5.1		1.0		
V-3S	O2	%	20.9	20.5	15.5	6	12		19.0		
V-3S	TNMHC	ppm	14900				6830				

Table C-8
(Continued)

Location	Analyte	Units	G0	G1	G2	G3	G4	G5	G6	G7	G8
V-3S	Total BTEX	ppm	600				378				
V-3S	Temperature	°C				24.5		13.7	13.8	41.1	33.7
V-4D	CO2	%			10.5	11		0.4	7.0	8.9	
V-4D	O2	%			4	7.5		20.9	9.5	8.5	
V-4D	TNMHC							17200		12800	
V-4D LD	TNMHC	ppm								12800	
V-4D	Total BTEX							1210		376.9	
V-4D LD	Total BTEX	ppm								378.5	
V-4S	CO2	%	13	0.5	0.8	5	2		0.3		
V-4S	O2	%	6	20.5	18	1.5	16		20.0		
V-4S	TNMHC	ppm	15400				5270				
V-4S	Total BTEX	ppm	489				453				
V-4S	Temperature	°C				21.1	6.9	10.7	13.8	21.0	18.6
V-5D	CO2	%			2.2	1.8			0.2		
V-5D	O2	%			19.5	20.5			21.0		
V-5D	Temperature	°C	0.0	1.2	0.1	0.0	0.6	6.7	2.0	5.3	2.3
V-5S	CO2	%	2.5	8	1.5	2	1.4	0.5	0.3	0.4	0.5
V-5S	O2	%	19	19	19	18.5	20	20.8	20.5	20.8	20.2
V-5S	TNMHC	ppm	2290				380				7.5
V-5S	Total BTEX	ppm	44.8				127				1.96
V-5S	Temperature	°C							0.2		2.1
V-6D	CO2	%			2	3	2.5	1.3	0.8	1.0	0.8
V-6D	O2	%			19.5	19	19	20.1	20.5	20.9	19.8
V-6D	TNMHC	ppm					9150	8570			1810
V-6D	Total BTEX	ppm					720	410			130
V-6D	Temperature	°C	-0.8	1.1	0.9	0.5	0.1	6.7	0.7	2.5	0.8
V-6S	CO2	%	3	0.5	0.5	0.3	0.4	1.3	0.2		
V-6S	O2	%	17	20.5	20.5	21	20.9	20.1	21.0		
V-6S	TNMHC	ppm	326			4.78	98.7				
V-6S	Total BTEX	ppm	12.6			0.210	23.0				
V-6S	Temperature	°C						6.7		2.7	0.4
V-7D	CO2	%			1.8	4	3.5	1.3	2.5	1.0	1.5
V-7D	O2	%			18.5	19	18.2	19.9	19.0	19.5	19.0
V-7D	TNMHC	ppm					430				3940
V-7D	Total BTEX	ppm					54.7				197
V-7D	Temperature	°C	-0.2	0.5	0.9		0.3	4.4		1.0	-0.3
V-7S	CO2	%	10	0.5	0.7	0.8	0.5		0.3	0.4	0.4
V-7S	O2	%	2.5	20.5	20.3	18	20.9		21.0	20.8	20.2

Table C-8
(Continued)

Location	Analyte	Units	G0	G1	G2	G3	G4	G5	G6	G7	G8
V-7S	TNMHC	ppm	2040								97.6
V-7S	Total BTEX	ppm	37.4								15.0
V-8D	CO2	%			3.7	4.2	4	1	0.4	2.6	4.0
V-8D	O2	%			16	18.5	16.2	20	16.5	17.0	15.8
V-8D	TNMHC	ppm					11000				16200
V-8D	Total BTEX	ppm					774				710
V-8S	CO2	%	1.5	0.5		2	0.7	0.6	0.5	0.6	0.7
V-8S	O2	%	18	20.5		18.5	20.5	20.9	21.0	20.7	20.0
V-8S	TNMHC	ppm	1560				3.04				0.37
V-8S	Total BTEX	ppm	31.7				0.14				0.02
V-8S	Temperature	°C				11.5	1.6			-2.1	0.4
V-9D	CO2	%			6.1	9			0.0	0.3	
V-9D	O2	%			12.3	9.5			20.5	20.8	
V-9S	CO2	%	16	0.5	2.8	3.8	3	1	0.3	0.8	0.7
V-9S	O2	%	3	20.5	17	9.5	18	20	20.0	20.0	19.0
V-9S	TNMHC	ppm	9080								56.3
V-9S	Total BTEX	ppm	439								5.79
V-9S	Temperature	°C				14.6			-0.3		
V-10D	CO2	%			3	8	5	4.5	1.5	1.9	2.5
V-10D	O2	%			17.3	11.5	12	15	19.5	18.8	17.6
V-10D	TNMHC	ppm									3970
V-10D	Total BTEX	ppm									205
V-10S	CO2	%	0.8	0.5	2.5						
V-10S	O2	%	20.9	20.5	17.5						
V-10S	TNMHC	ppm	6.17								
V-10S	Total BTEX	ppm	1.75								
V-10S	Temperature	°C	7.5			16.1					

FD = Field duplicate
LD = Lab duplicate
FD/LD = Lab duplicate of Field duplicate

APPENDIX C.3

SVE Flow Rate Calculations

RADIAN CORPORATION

CALCULATION SHEET

CALC. NO.

SIGNATURE M A Robbins DATE 9/14/93 CHECKED CSH DATE 12/3/93

PROJECT GALENA TS JOB NO.

SUBJECT SVE Flow Calculation SHEET 1 OF 8 SHEETS

THE Flow through the Soil Vapor Extraction System is measured through the use of a pitot tube device and a magnehelic pressure gauge that measures the differential between the static and Total pressure to give the velocity pressure.

The Equation for this calculation is

$V = 1096.2\sqrt{h_v/d}$ where

V = velocity in (FT/min)

h_v = differential pressure (in of H_2O)

d = density of Air at measured conditions

d (for Vacuum conditions) = 0.075 lbs/ft³ * Pressure Factor * Temp Factor

$$\text{Pressure Factor} = \frac{\text{Vacuum (in Hg)} + \text{Baro Pressure (in Hg)}}{29.92 \text{ in Hg}}$$

$$\text{Temp Factor} = \frac{(68°F + 460)}{(\text{Flow temp} + 460)}$$

Finally

$Q = AV$

A = Area of Pipe (ft²) $= \frac{\pi D^2}{4}$

Because the velocity is not equivalent across the section of a pipe the pitot tube was placed in the center of the pipe and the resulting calculated flow is multiplied by 0.9 to obtain the average

So $Q_{Avg} = 0.9AV$

RADIAN
CORPORATION

CALCULATION SHEET

CALC. NO.

SIGNATURE M A Robbins DATE 9/14/93 CHECKED CSH DATE 12/3/93

PROJECT Galena TS JOB NO.

SUBJECT SVE Flow Calculation SHEET 2 OF 8 SHEETS

Example 8

DATA

Vacuum = 70 in H_2O
Diff P = 7.5 in H_2O
Baro P = 756.5 mm Hg
Temp = 49° F
Pipe Dia = 1.91 in

$$d = 0.075\ \text{lbs/FT}^3 \left[\frac{\left(\frac{70\ \text{in}\ H_2O}{13.6''\ H_2O/\text{in Hg}} + 29.78''\ \text{Hg} \right)}{29.92''\ \text{Hg}} * \left(528\ °R / (49 + 460)°R \right) \right]$$

$$= 0.075\ \text{lb/FT}^3\ (1.163)(1.037)$$

$$\underline{d} = 0.0908\ \text{lbs/FT}^3$$

$$V = 1096.7 \sqrt{7.5/0.0908}$$

$$V = 9967\ \text{FT/min}$$

$$Q = \left(\frac{3.14 (1.91/12)^2}{4} \right) * 9967 * 0.9$$

$$Q_{\text{Actual}} = 178\ \text{cfm}$$

To convert from Actual conditions to Standard use the ideal gas formula

$$\frac{VP}{T} = \frac{VP}{T}$$

$$\text{Scfm} = \text{ACFM} * \left(\frac{29.78}{29.92} \right) * \frac{528\ °R}{509\ °R} = 183.8\ \text{scfm}$$

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Date	Date	Running Tim	Exhaust Ten	System Vac	Inlet Flow (5	Exhaust Flo	Inlet Temp (4	Exhaust Bac	HC Cond	Time		Inlet Flow Density	Air Velocity	ACFM	SCFM	Outlet Flow Density	Air Velocity	ACFM	SCFM
Date	Date	Running Tim	Exhaust Ten	System Vac	Inlet Flow (5	Exhaust Flo	Inlet Temp (4	Exhaust Bac	HC Cond	Time		Inlet Flow Density	Air Velocity	ACFM	SCFM	Outlet Flow Density	Air Velocity	ACFM	SCFM
08/03/93	08/03/93	0	146	74	5.9	0.39	50	0.35		09:45									
08/04/93	08/04/93	18	147	75	5.5	0.4	51	0.3		17:00	29.85	0.09158	8494.94	152.12	156.79	0.06405	2740.59	129.28	112.17
08/05/93	08/05/93	7	147	75	5	0.4	52	0.23		17:20	29.94	0.09165	8096.66	144.99	149.62	0.06395	2742.81	129.39	112.62
08/06/93	08/06/93	22	142	76	5	0.4	52	0.3		17:25	29.96	0.09188	8086.57	144.81	149.51	0.06451	2730.79	128.82	113.12
08/07/93	08/07/93	24	150	76	5	0.4	52	0.3		17:00	30.01	0.09202	8080.32	144.70	149.67	0.06379	2746.30	129.55	112.47
08/08/93	08/08/93	17	146	75	5	0.4	51.5	0.3		18:20	29.98	0.09184	8088.15	144.84	149.81	0.06459	2729.24	128.75	112.40
08/09/93	08/09/93	22	154	76	5	0.4	58	0.2		17:00	29.97	0.09084	8132.67	145.64	148.67	0.06306	2762.20	130.30	112.22
08/10/93	08/10/93	22	140	72	6.3	0.45	65	0.35		18:55	29.79	0.08845	9251.62	165.67	165.90	0.06459	2894.75	136.55	119.65
08/11/93	08/11/93	13	142	76	5	0.35	53	0.25		18:40	29.71	0.09107	8122.51	145.45	148.66	0.06420	2560.68	120.79	105.20
08/12/93	08/12/93	9	142	76	5	0.35	53	0.25			29.64	0.09089	8130.57	145.60	148.45	0.06405	2563.75	120.94	105.08
08/13/93	08/13/93	12	142	76	5	0.35	53	0.25		07:00	29.35	0.09013	8164.83	146.21	147.60	0.06340	2576.83	121.56	104.57
08/14/93	08/14/93	12	142	76	5	0.35	53	0.25		07:15	29.07	0.08942	8197.16	146.79	146.79	0.06257	2593.84	122.36	104.27
08/15/93	08/15/93	24	143	75	4.9	0.3	47	0.3		08:00	29.39	0.09112	8038.65	143.95	147.26	0.06317	2390.02	112.74	96.97
08/16/93	08/16/93	24	140	76	5	0.35	46	0.3		10:30	29.50	0.09178	8091.01	144.89	149.07	0.06418	2561.17	120.82	104.83
08/17/93	08/17/93	24	154	74	4.9	0.4	57	0.2		07:30	29.53	0.08951	8110.40	145.24	146.37	0.06277	2768.57	130.60	110.83
08/18/93	08/18/93	24	152	74	5	0.4	54	0.2	1200	07:42	29.21	0.08923	8205.98	146.95	147.37	0.06229	2779.14	131.10	110.42
08/19/93	08/19/93	24	157	72	4.9	0.35	56	0.2	1100	07:45	29.35	0.08885	8140.71	145.78	146.30	0.06186	2608.74	123.06	103.29
08/20/93	08/20/93	12	148	71	5.9	0.4	60	0.25	600	07:30	29.49	0.08833	8958.82	160.43	160.53	0.06330	2756.91	130.05	111.30
08/21/93	08/21/93	18	153	72	5	0.4	56	0.2	1300	08:20	29.69	0.08973	8182.71	146.53	148.79	0.06278	2768.16	130.58	111.61
08/22/93	08/22/93	21	143	72	5.5	0.35	50	0.3	1000	07:45	29.80	0.09107	8518.68	152.55	157.30	0.06429	2558.86	120.71	105.27
08/23/93	08/23/93	20	142	72	5.6	0.35	50	0.25	1100	07:30	29.86	0.09123	8588.43	153.80	158.91	0.06386	2567.52	121.12	106.02
08/24/93	08/24/93	22	140	75	5.4	0.3	42	0.4	1200	07:30	29.87	0.09329	8339.96	149.35	156.82	0.06454	2364.43	111.54	97.99
08/25/93	08/25/93	12	124	74	6	0.3	45	0.3	450	07:10	29.90	0.09261	8823.37	158.00	165.06	0.06591	2339.84	110.38	99.71
08/26/93	08/26/93	24	158	63	5.5	0.4	63	0.4	950	11:15	29.91	0.08741	8695.19	155.71	157.15	0.06253	2773.79	130.85	111.75
08/27/93	08/27/93	21	161	72	5.5	0.4	69	0.35	1000	15:05	29.92	0.08809	8661.73	155.11	154.79	0.06224	2780.28	131.15	111.49
08/28/93	08/28/93	24	155	69	5.5	0.4	65	0.35	1100	08:00	29.88	0.08812	8660.41	155.09	155.76	0.06299	2763.65	130.37	111.78
08/29/93	08/29/93	24	150	66	5.5	0.35	61	0.3	1200	08:30	29.74	0.08787	8672.83	155.31	156.42	0.06319	2581.03	121.75	104.74
08/30/93	08/30/93	24	153	66	5.5	0.4	63	0.3	1000	10:50	29.69	0.08742	8695.12	155.71	155.99	0.06300	2763.32	130.35	111.42
08/31/93	08/31/93	24	159	71	5.3	0.4	69	0.25	1100	09:15	29.00	0.08562	8624.72	154.45	149.42	0.06061	2817.29	132.90	109.88
09/01/93	09/01/93	21	150	70	5.5	0.38	60	0.32		08:30	29.355	0.08782	8675.28	155.35	154.76	0.06192	2716.73	128.16	108.83
09/02/93	09/02/93	6	146	68	6.1	0.43	60	0.4		18:06	29.485	0.08777	9138.49	163.65	163.75	0.06257	2874.94	135.62	116.45
09/03/93	09/03/93	16	138	68	6.3	0.43	50	0.41		10:45	29.75	0.09018	9162.23	164.07	168.90	0.06409	2840.78	134.01	117.65
09/04/93	09/04/93	24	140	70	6	0.39	52	0.39	2000	09:00	29.94	0.09070	8915.80	159.66	164.76	0.06438	2699.21	127.33	112.13
09/05/93	09/05/93	24	140	71	5.8	0.42	51	0.37	1400	09:50	29.795	0.09069	8766.31	156.98	161.53	0.06348	2820.98	133.07	116.62
09/06/93	09/06/93	24	160	69	5.8	0.4	62	0.5		09:20	29.14	0.08675	8963.41	160.51	158.13	0.06047	2820.71	133.06	110.36
09/07/93	09/07/93	24	146	70	5.8	0.4	58	0.4	1400	13:20	29.38	0.08822	8888.37	159.17	159.31	0.06239	2776.94	131.00	112.08
09/08/93	09/08/93	24	138	72	5.8	0.4	50	0.4	1600	07:45	30.055	0.09174	8716.31	156.09	162.33	0.06472	2726.52	128.62	114.07
09/09/93	09/09/93	24	149	72	5.5	0.4	59	0.4	1100	19:30	29.8	0.08950	8593.52	153.89	155.93	0.06344	2753.91	129.91	112.18
09/10/93	09/10/93	24	148	73	5.3	0.35	58	0.3	1000	18:30	30.08	0.09057	8385.56	150.16	153.88	0.06459	2552.87	120.43	105.14
09/11/93	09/11/93	24	150	73	5.2	0.4	56	0.2	820	14:45	29.75	0.09008	8328.88	149.15	151.75	0.06322	2758.53	130.13	112.00
09/12/93	09/12/93	16	142	72	5.2	0.35	52	0.3	28	08:20	29.56	0.09010	8327.84	149.13	151.94	0.06387	2567.28	121.11	104.94
09/13/93	09/13/93	12	149	75	5	0.35	52	0.25	650	11:00	29.89	0.09152	8102.38	145.09	149.48	0.06407	2563.18	120.91	104.73
09/14/93	09/14/93	14	150	82.5	5	0.4	58	0.2	746	08:50	29.79	0.09162	8098.24	145.02	147.18	0.06331	2756.64	130.04	112.07
09/15/93	09/15/93	12	154	76	4.8	0.3	53	0.3	620	08:44	29.7	0.09104	7959.53	142.54	145.62	0.06270	2398.84	113.16	96.59
09/16/93	09/16/93	10	153	77	4.7	0.3	56	0.3	500	08:21	29.35	0.08980	7930.30	142.01	142.55	0.06249	2402.93	113.35	95.78
09/17/93	09/17/93	10	142	78	4.9	0.25	48	0.2	350	08:30	29.875	0.09278	7966.46	142.66	148.05	0.06479	2154.35	101.63	89.00
09/18/93	09/18/93	15	133	82	4.8	0.25	50	0.2	350	13:30	29.835	0.09307	7872.21	140.97	145.53	0.06523	2147.08	101.28	89.93
09/19/93	09/19/93	9	103	83	4.4	0.3	57	0.3	160	007:59	29.4	0.09089	7627.15	136.58	137.07	0.06864	2292.83	108.16	99.67
09/20/93	09/20/93	12	142	81	4.3	0.25	45	0.1	28	08:23	29.28	0.09235	7480.15	133.95	137.06	0.06348	2176.43	102.67	88.12
09/21/93	09/21/93	12	82	82	4.8	0.2	46	0.2	180	08:10	29.37	0.09259	7892.61	141.34	144.77	0.07073	1844.23	87.00	83.19
09/22/93	09/22/93	12	142	82	4.6	0.2	40	0.2	290	08:15	29.905	0.09512	7623.10	136.51	144.08	0.06217	1967.09	92.79	81.35
09/23/93	09/23/93	12	90	40	2	0.3	44	0.8	110	08:00	29.87	0.08616	5281.32	94.58	98.91	0.06845	2295.95	108.31	103.80
09/24/93	09/24/93	24	110	42	1.6	0.3	46	0.7	230	08:30	29.85	0.08616	4723.98	84.59	88.07	0.06600	2338.15	110.30	101.93
09/25/93	09/25/93	24	108	44	1.4	0.6	42	0.7	220	07:20	29.79	0.08707	4395.57	78.71	82.43	0.06609	3304.32	155.87	144.27
09/26/93	09/26/93	12	110	46	1	0.4	38	0.7	180	08:10	29.81	0.08821	3690.78	66.09	69.82	0.06591	2701.76	127.45	117.62
09/27/93	09/27/93	12	125	42	1	0.4	60	0.7	210	08:00	30.155	0.08461	3768.54	67.49	69.06	0.06546	2711.00	127.89	116.33
09/28/93	09/28/93	24	164	44	1	0.6	95	0.6	240	10:40	29.6	0.07830	3917.41	70.15	66.02	0.06019	3462.55	163.34	136.73
09/29/93	09/29/93	24	116	56	0.9	0.5	44	0.6	300	07:10	29.67	0.08873	3491.25	62.52	64.95	0.06584	3022.32	142.57	129.60
09/30/93	09/30/93	24	165	56	1	0.6	88	0.5	120	07:10	29.02	0.08003	3874.83	69.39	64.85	0.05973	3475.92	163.97	134.35
10/01/93	10/01/93	24	180	58	1	0.6	95	0.4	240	08:00	29.23	0.07988	3878.66	69.46	64.55	0.05876	3504.36	165.31	133.24
10/02/93	10/02/93	16	150	66	1.7	0.5	80	0.4	82	09:15	29.62	0.08449	4917.06	88.05	85.23	0.06162	3124.10	147.37	126.28
10/03/93	10/03/93	12	160	54	1.7	0.65	80	0.6	260	08:09	30.05	0.08338	4949.64	88.64	87.04	0.06111	3576.87	168.73	144.32
10/04/93	10/04/93	20	146	45	1.3	0.5	84	0.7	445	07:31	30	0.08104	4390.51	78.62	76.51	0.06241	3104.22	146.43	127.93
10/05/93	10/05/93	14	156	42	1.6	0.45	92	0.7	360	09:15	29.62	0.07842	4951.35	88.67	83.96	0.06364	2916.25	137.57	116.73
10/06/93	10/06/93	2								08:45	29.54	0.08499	0.00	0.00	0.00	0.08499	0.00	0.00	0.00
10/07/93	10/07/93	0								08:30	29.5	0.08488	0.00	0.00	0.00	0.08107	0.00	0.00	0.00
10/08/93	10/08/93	15	148	38	2.4	0.8	90	0.65	400	08:30	29.4	0.07747	6101.29	109.26	103.07	0.06134	3960.60	186.83	159.43
10/09/93	10/09/93	24	162	50	3.9	0.6	90	0.6	450	08:15	29.5	0.07984	7661.64	137.20	129.86	0.06147	3426.29	161.63	135.28
10/10/93	10/10/93	24	154	50	4	0.6	94	0.3	450	08:30	29.8	0.07998	7752.43	138.83	131.78	0.06160	3422.65	161.46	138.29
10/11/93	10/11/93	12	164	50	3.9	0.65	91	0.6	400	08:00	29.5	0.07969	7668.60	137.33	129.75	0.05998	3610.30	170.31	142.08
10/12/93	10/12/93	12	168	50	3.8	0.7	96	0.6	800	08:15	29.2	0.07826	7638.53	136.79	126.77	0.05939	3765.00	177.61	145.73
10/13/93	10/13/93	24	122	60	4.6	0.6	54	0.5	1300	08:10	29.91	0.08838	7908.58	141.62	145.43	0.06570	3314.13	156.34	141.78
10/14/93	10/14/93	24	135	61	4.6	0.5	55	0.5	420	08:15	29.39	0.08706	7968.27	142.69	143.70	0.06311	3086.88	145.62	126.93
10/15/93	10/15/93	24	134	60	4.6	0.6	56	0.5		08:20	29.87	0.08793	7928.58	141.98	145.04	0.06429	3350.45	158.05	140.25

Date	Date	Running Tim	Exhaust Ten	System Vac	Inlet Flow (5	Exhaust Flo	Inlet Temp (4	Exhaust Bad	HC Cond	Time		Inlet Flow Density	Air Velocity	ACFM	SCFM	Outlet Flow Density	Air Velocity	ACFM	SCFM
10/16/93	10/16/93	24	162	58	4.8	0.7	85	0.5	2000	08:30	29.89	0.08294	8339.05	149.33	144.53	0.06144	3701.92	174.63	148.09
10/17/93	10/17/93	24	130	61	4.6	0.6	52	0.5	1600	08:15	29.39	0.08757	7945.03	142.28	144.12	0.06365	3367.27	158.84	139.63
10/18/93	10/18/93	24	130	60	4.8	0.6	54	0.5	2200	08:10	29.39	0.08704	8140.58	145.78	147.10	0.06365	3367.27	158.84	139.63
10/19/93	10/19/93	24	128	60	4.8	0.6	50	0.5	2400	08:20	29.89	0.08902	8049.53	144.15	149.09	0.06499	3332.33	157.20	141.01
10/20/93	10/20/93	24	130	60	4.8	0.6	52	0.5	2600	08:10	29.59	0.08790	8100.80	145.07	147.95	0.06409	3355.47	158.29	140.09
10/21/93	10/21/93	24	122	60	4.8	0.5	45	0.5	3500	08:20	29.68	0.08935	8034.61	143.88	149.23	0.06518	3037.49	143.29	128.95
10/22/93	10/22/93	24	115	60	4.8	0.5	60	0.5	2800	09:10	29.42	0.08611	8184.33	146.56	146.33	0.06538	3032.96	143.07	129.18
10/23/93	10/23/93	24	119	60	5	0.6	41	0.5	3200	08:45	29.69	0.09009	8166.55	146.24	152.94	0.06554	3318.24	156.53	141.65
10/24/93	10/24/93	24	156	60	5.4	0.7	80	0.5	3400	10:00	29.39	0.08285	8850.08	158.48	152.22	0.06096	3716.35	175.31	147.60
10/25/93	10/25/93	24	135	60	5.5	0.6	58	0.5	3600	08:10	30.04	0.08803	8664.90	155.17	158.80	0.06456	3343.43	157.72	140.52
10/26/93	10/26/93	24	132	61	5.4	0.6	54	0.5	4000	08:10	30.05	0.08893	8542.20	152.97	157.82	0.06491	3334.42	157.29	140.90
10/27/93	10/27/93	24	142	60	5.6	0.6	66	0.5	4000	08:20	30.04	0.08669	8810.57	157.78	159.01	0.06381	3363.04	158.64	139.70
10/28/93	10/28/93	12	142	60	6	0.5	64	0.5	6000	08:15	30.01	0.08694	9106.42	163.07	164.81	0.06374	3071.61	144.90	127.47
10/29/93	10/29/93	12	144	60	7	0.5	66	0.5	6000	08:20	29.94	0.08644	9864.85	176.66	177.45	0.06338	3080.43	145.31	127.11
10/30/93	10/30/93	24	146	60	7.5	0.5	56	0.5	2800	09:20	29.78	0.08770	10137.19	181.53	184.88	0.06282	3094.09	145.96	126.58
10/31/93	10/31/93	24	128	60	7.5	0.3	51	0.5	1800	08:30	29.76	0.08851	10090.91	180.70	185.72	0.06470	2361.63	111.41	99.50
11/01/93	11/01/93	16	110	60	7	0.4	46	0.5	800	08:10	29.74	0.08933	9703.77	173.77	180.24	0.06669	2685.85	126.70	116.66
11/02/93	11/02/93	12	134	60	7.5	0.4	44	0.5	5700	08:20	29.86	0.09000	10006.93	179.20	187.36	0.06426	2736.10	129.07	114.50
11/03/93	11/03/93	24	134	60	7.2	0.7	48	0.5	6000	09:30	30.04	0.08976	9817.83	175.81	183.47	0.06421	3621.01	170.81	152.44
11/04/93	11/04/93	21	143	60	7.3	0.7	58	0.6	4800	09:25	29.95	0.08780	9995.66	179.00	182.64	0.06306	3654.05	172.37	151.08
11/05/93	11/05/93	24	135	60	7.2	0.6	49	0.6	5000	09:30	29.97	0.08940	9837.48	176.17	183.05	0.06440	3347.47	157.91	140.36
11/06/93	11/06/93	24	150	60	7.4	0.7	68	0.5	4600	12:00	29.84	0.08586	10176.87	182.24	181.76	0.06254	3669.22	173.09	149.42
11/07/93	11/07/93	24	140	61	7.4	0.7	54	0.5	4800	09:35	29.89	0.08852	10022.99	179.49	184.19	0.06369	3635.87	171.51	150.78
11/08/93	11/08/93	24	140	61	7.5	0.7	55	0.5	4600	08:20	29.89	0.08834	10100.29	180.87	185.25	0.06369	3635.87	171.51	150.78
11/09/93	11/09/93	24	140	61	7.2	0.7	56	0.5	4600	08:00	29.34	0.08676	9986.04	178.83	179.44	0.06247	3671.00	173.17	149.44
11/10/93	11/10/93	24	136	61	7.2	0.7	48	0.5	4400	09:40	29.55	0.08867	9877.71	176.89	181.58	0.06336	3645.25	171.96	150.45
11/11/93	11/11/93	24	140	58	7.9	0.7	96	0.5	450	09:35	29.34	0.07999	10893.66	195.08	181.66	0.06247	3671.00	173.17	149.44
11/12/93	11/12/93	24	144	62	7.9	0.7	60	0.5	4200	10:30	29.42	0.08648	10476.93	187.62	187.32	0.06224	3678.03	173.50	149.14
11/13/93	11/13/93	24	142	64	7.9	0.7	56	0.5	4600	09:20	29.32	0.08728	10429.34	186.76	187.27	0.06222	3678.41	173.52	149.14
11/14/93	11/14/93	24	140	64	7.6	0.7	54	0.5	4500	10:15	29.42	0.08787	10194.58	182.56	184.40	0.06265	3665.83	172.93	149.63
11/15/93	11/15/93	24	138	65	7.8	0.65	50	0.5	4600	08:20	29.84	0.08984	10213.99	182.91	188.86	0.06379	3500.80	165.14	145.42
11/16/93	11/16/93	24	140	65	7.8	0.7	50	0.5	4400	15:30	29.89	0.08997	10206.62	182.78	189.04	0.06369	3635.87	171.51	150.78
11/17/93	11/17/93	24	140	66	7.8	0.7	50	0.5	4600	08:20	29.98	0.09040	10182.64	182.35	189.16	0.06389	3630.21	171.25	151.00
11/18/93	11/18/93	24	136	66	7.8	0.6	48	0.5	4600	08:05	29.73	0.09010	10199.32	182.64	188.63	0.06376	3364.25	158.70	139.70
11/19/93	11/19/93	24	141	66	8	0.65	52	0.5	4400	15:30	29.92	0.08989	10341.47	185.19	190.98	0.06365	3504.71	165.33	145.25
11/20/93	11/20/93	24	142	66	7.8	0.65	54	0.5	4200	10:40	30.21	0.09029	10188.91	182.46	189.24	0.06418	3490.16	164.64	145.80
11/21/93	11/21/93	24	145	63	7.9	0.7	64	0.5	4300	10:30	29.58	0.08641	10481.19	187.69	186.98	0.06248	3670.74	173.16	149.40
11/22/93	11/22/93	12	148	60	8	0.7	74	0.5	520	08:20	29.72	0.08460	10660.05	190.90	187.49	0.06248	3670.85	173.16	149.37
11/23/93	11/23/93	24	130	64	7.8	0.7	38	0.5	4500	08:20	29.41	0.09067	10167.32	182.07	189.75	0.06369	3635.79	171.51	150.87
11/24/93	11/24/93	24	148	64	8	0.7	62	0.5	3800	14:25	29.96	0.08790	10458.08	187.28	189.68	0.06300	3655.60	172.45	149.96
11/25/93	11/25/93	24	137	63	8.5	0.6	56	0.5	2050	15:30	29.91	0.08860	10736.96	192.27	196.68	0.06405	3356.57	158.34	139.99
11/26/93	11/26/93	8	125	62	8.5	0.5	50	0.5	300	16:38	29.86	0.08932	10693.49	191.49	197.86	0.06525	3035.79	143.21	128.99
11/27/93	11/27/93	9	124	62	8.4	0.6	52	0.5	400	10:30	29.92	0.08913	10641.95	190.57	196.53	0.06550	3319.25	156.58	141.56
11/28/93	11/28/93	10	146	60	8.3	0.7	78	0.5	230	11:20	29.72	0.08397	10898.68	195.17	190.26	0.06269	3664.81	172.88	149.62
11/29/93	11/29/93	21	138	62	8.4	0.6	63	0.5	2215	08:00	29.4	0.08594	10837.70	194.08	192.53	0.06282	3389.43	159.89	138.72
11/30/93	11/30/93	18	138	62	8.4	0.6	63	0.5	2215	08:00	29.4	0.08594	10837.70	194.08	192.53	0.06282	3389.43	159.89	138.72
12/01/93	12/01/93	0	138	62	8.4	0.6	63	0.5	2215	08:00	29.4	0.08594	10837.70	194.08	192.53	0.06507	3330.23	157.10	136.30
12/02/93	12/02/93	8								08:20	29.12	0.08379	0.00	0.00	0.00	0.08086	0.00	0.00	0.00
12/03/93	12/03/93	20	130	64	8.4	0.5	48	0.5	4200	08:25	29.52	0.08917	10639.40	190.53	195.38	0.06394	3066.87	144.67	127.74
12/04/93	12/04/93	24	131	64	8.5	0.5	58	0.5	4200	09:20	29.62	0.08771	10791.62	193.25	195.01	0.06405	3064.10	144.54	127.84
12/05/93	12/05/93	24	130	64	8.4	0.5	60	0.5	4200	10:20	29.32	0.08660	10795.92	193.33	192.37	0.06577	3023.78	142.64	125.09
12/06/93	12/06/93	13								08:10	29	0.08344	0.00	0.00	0.00	0.08051	0.00	0.00	0.00
12/07/93	12/07/93	24	136	62	8.1	0.6	49	0.5	3800	11:30	28.35	0.08557	10665.18	190.99	187.72	0.06047	3454.58	162.96	136.79
12/08/93	12/08/93	24	134	61	8.1	0.55	46	0.55	4000	11:00	29.01	0.08761	10540.20	188.75	190.97	0.06214	3262.65	153.91	132.65
12/09/93	12/09/93	20	140	62	8.3	0.6	51	0.55	4400		29.5	0.08821	10633.05	190.41	193.98	0.06260	3395.20	160.16	138.96
12/10/93	12/10/93	24	146	62	8.5	0.6	55	0.55	4400	16:30	29.5	0.08753	10802.42	193.45	195.54	0.06221	3406.03	160.67	138.03
12/11/93	12/11/93	17	138	60	8.2	0.5	58	0.5	4800	09:40	29.75	0.08729	10624.90	190.27	192.84	0.06359	3075.21	145.07	127.36
12/12/93	12/12/93	24	146	60	8.4	0.6	60	0.5	4800	16:30	29.42	0.08611	10826.85	193.88	193.58	0.06203	3410.82	160.90	137.85
12/13/93	12/13/93	24	134	60	8.2	0.5	48	0.5	5100	12:40	29.49	0.08833	10562.11	189.14	193.76	0.06344	3078.87	145.24	127.25
12/14/93	12/14/93	24	134	60	8.4	0.5	46	0.5	4800	9:35	29.58	0.08891	10654.94	190.80	196.84	0.06364	3074.01	145.01	127.43
12/15/93	12/15/93	24	134	60	8.2	0.5	46	0.5	4600	12:00	29.58	0.08891	10527.33	188.52	194.48	0.06364	3074.01	145.01	127.43
12/16/93	12/16/93	24	134	62	8.4	0.5	46	0.5	4600	12:15	29.56	0.08924	10635.08	190.45	196.34	0.06360	3075.09	145.06	127.39
12/17/93	12/17/93	24	124	60	8.6	0.6	82	0.5	0		29.5	0.08281	11171.12	200.05	192.14	0.06455	3343.63	157.73	140.60
12/18/93	12/18/93	24	133	60	8.8	0.55		0.5	3000		29.3	0.09700	10441.25	186.98	210.17	0.06312	3237.24	152.71	133.15
12/19/93	12/19/93	24	141	60	9	0.5	62	0.5	3000		29.02	0.08477	11295.35	202.27	198.44	0.06167	3122.84	147.31	125.53
12/20/93	12/20/93	24	141	60	9.5	0.5	62	0.5	2750		29.2	0.08522	11573.76	207.26	204.60	0.06206	3112.85	146.84	125.90
12/21/93	12/21/93	24	140	60	10	0.5	62	0.5	2500	09:30	29.35	0.08560	11848.02	212.17	210.52	0.06250	3102.01	146.33	126.32
12/22/93	12/22/93	24	140	60	10	0.5	62	0.5	2750		29.3	0.08548	11856.80	212.33	210.32	0.06239	3104.76	146.46	126.21
12/23/93	12/23/93	24	139	60	10	0.5	61	0.5	3000	10:20	29.32	0.08569	11841.93	212.06	210.60	0.06253	3101.07	146.29	126.36
12/24/93	12/24/93	24	140	60	10	0.5	62	0.5	3000		29.5	0.08598	11821.78	211.70	211.13	0.06283	3093.84	145.95	126.63
12/25/93	12/25/93	24	140	60	10	0.5	62	0.5	3000		29.5	0.08598	11821.78	211.70	211.13	0.06283	3093.84	145.95	126.63
12/26/93	12/26/93	24	140	60	10	0.5	62	0.5	3000		29.5	0.08598	11821.78	211.70	211.13	0.06283	3093.84	145.95	126.63
12/27/93	12/27/93	24	140	60	10	0.5	62	0.5	3000		29.5	0.08598	11821.78	211.70	211.13	0.06283	3093.84	145.95	126.63
12/28/93	12/28/93	24	141	60	10	0.5	62	0.5	3000	12:00	29.76	0.08664	11776.73	210.89	212.18	0.06330	3082.38	145.40	127.06
12/29/93	12/29/93	24	140	60	10	0.5	62	0.5	3000		29.5	0.08598	11821.78	211.70	211.13	0.06283	3093.84	145.95	126.63

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Date	Date	Running Tim	Exhaust Ten	System Vac	Inlet Flow (5	Exhaust Flo	Inlet Temp (4	Exhaust Bac	HC Cond	Time		Inlet Flow Density	Air Velocity	ACFM	SCFM	Outlet Flow Density	Air Velocity	ACFM	SCFM
12/30/93	12/30/93	24	140	60	10	0.5	62	0.5	3000		29.5	0.08598	11821.78	211.70	211.13	0.06283	3093.84	145.95	126.63
12/31/93	12/31/93	24	140	60	10	0.5	62	0.5	3000		29.5	0.08598	11821.78	211.70	211.13	0.06283	3093.84	145.95	126.63
01/01/94	01/01/94	24	140	60	10	0.5	62	0.5	3000		29.5	0.08598	11821.78	211.70	211.13	0.06283	3093.84	145.95	126.63
01/02/94	01/02/94	24	140	60	10	0.5	62	0.5	3000		29.5	0.08598	11821.78	211.70	211.13	0.06283	3093.84	145.95	126.63
01/03/94	01/03/94	24	140	60	10	0.5	62	0.5	3000		29.5	0.08598	11821.78	211.70	211.13	0.06283	3093.84	145.95	126.63
01/04/94	01/04/94	24	140	60	10	0.5	62	0.5	3000		29.5	0.08598	11821.78	211.70	211.13	0.06283	3093.84	145.95	126.63
01/05/94	01/05/94	24	140	60	10	0.5	62	0.5	3000		29.5	0.08598	11821.78	211.70	211.13	0.06507	3039.98	143.40	124.42
01/06/94	01/06/94	6									29.5	0.08488	0.00	0.00	0.00	0.08488	0.00	0.00	0.00
01/07/94	01/07/94	0									29.9	0.08603	0.00	0.00	0.00	0.08603	0.00	0.00	0.00
01/08/94	01/08/94	0									29.9	0.08603	0.00	0.00	0.00	0.08251	0.00	0.00	0.00
01/09/94	01/09/94	0	132	62	8.4	0.4	44	0.6	1500	14:00	29.9	0.09049	10561.55	189.13	198.01	0.06412	2739.27	129.22	115.17
01/10/94	01/10/94	12	135	61	8.5	0.5	52	0.6	550	8:45	29.9	0.08889	10719.66	191.96	197.83	0.06402	3064.92	144.58	128.21
01/11/94	01/11/94	24	134	62	8.5	0.5	50	0.55	4200		29.95	0.08956	10679.54	191.24	198.19	0.06424	3059.68	144.33	128.43
01/12/94	01/12/94	24	134	62	8.5	0.5	50	0.55	4200		29.95	0.08956	10679.54	191.24	198.19	0.06447	3054.29	144.08	128.20
01/13/94	01/13/94	24	132	62	8.5	0.5	48	0.5	4300	9:20	30.02	0.09009	10647.78	190.68	198.85	0.06484	3045.47	143.66	128.56
01/14/94	01/14/94	24	132	62	8.6	0.5	47	0.5	4200	9:50	29.95	0.09009	10710.53	191.80	199.94	0.06468	3049.15	143.84	128.42
01/15/94	01/15/94	24	132	62	8.6	0.5	46	0.5	4200	8:40	30.02	0.09045	10689.13	191.42	200.41	0.06484	3045.47	143.66	128.56
01/16/94	01/16/94	24	133	62	8.6	0.5	46	0.5	4350	8:45	30.08	0.09060	10679.87	191.25	200.63	0.06486	3044.89	143.64	128.58
01/17/94	01/17/94	24	133	62	8.5	0.5	46	0.5	4200	10:15	30.01	0.09042	10628.34	190.33	199.20	0.06471	3048.56	143.81	128.43
01/18/94	01/18/94	24	130	62	8.7	0.5	47	0.5	4300	8:45	29.95	0.09009	10772.62	192.91	201.10	0.06490	3043.99	143.59	128.63
01/19/94	01/19/94	24	132	62	8.6	0.5	46	0.5	4250	10:35	29.95	0.09026	10699.97	191.61	200.14	0.06468	3049.15	143.84	128.42
01/20/94	01/20/94	24	132	62	8.6	0.5	46	0.5	4250	10:00	29.89	0.09011	10709.28	191.78	199.91	0.06455	3052.31	143.99	128.29
01/21/94	01/21/94	24	132	62	8.7	0.6	46	0.5	4300	9:40	29.96	0.09029	10760.44	192.69	201.34	0.06471	3339.60	157.54	140.70
01/22/94	01/22/94	24	132	62	8.6	0.5	48	0.5	4300	10:20	30.01	0.09006	10711.78	191.82	199.97	0.06482	3045.99	143.69	128.54
01/23/94	01/23/94	24	133	62	8.6	0.5	47	0.5	4250	9:20	29.98	0.09016	10705.88	191.72	200.06	0.06464	3050.14	143.88	128.37
01/24/94	01/24/94	24	132	62	8.6	0.5	47	0.5	4250	8:40	29.95	0.09009	10710.53	191.80	199.94	0.06468	3049.15	143.84	128.42
01/25/94	01/25/94	24	133	62	8.6	0.5	50	0.5	4300	11:00	29.85	0.08930	10757.77	192.65	198.98	0.06435	3057.01	144.21	128.10
01/26/94	01/26/94	24	132	62	8.7	0.5	52	0.5	4250	8:45	29.52	0.08809	10893.70	195.08	198.49	0.06372	3072.06	144.92	127.52
01/27/94	01/27/94	24	133	62	8.7	0.6	50	0.5	4250	8:40	29.59	0.08862	10861.25	194.50	199.14	0.06377	3363.99	158.69	139.74
01/28/94	01/28/94	24	133	62	8.8	0.5	51	0.5	4300	8:50	29.85	0.08912	10892.81	195.06	201.08	0.06435	3057.01	144.21	128.10
01/29/94	01/29/94	24	136	62	8.8	0.5	60	0.5	4300	10:50	29.8	0.08745	10996.31	196.92	199.14	0.06392	3067.39	144.70	127.67
01/30/94	01/30/94	24	137	62	8.8	0.5	63	0.5	4300	9:20	29.87	0.08713	11016.77	197.28	198.84	0.06396	3066.24	144.64	127.71
01/31/94	01/31/94	12	129	62	8.5	0.5	75	0.5		8:20	29.95	0.08537	10938.16	195.88	193.51	0.06501	3041.41	143.47	128.74
02/01/94	02/01/94	24	130	62	8.8	0.5	75	0.5	4350	8:15	29.95	0.08537	11129.51	199.30	196.89	0.06490	3043.99	143.59	128.63
02/02/94	02/02/94	24	130	62	8.8	0.5	72	0.5	4300	8:40	29.98	0.08593	11093.44	198.66	197.56	0.06497	3042.42	143.52	128.70
02/03/94	02/03/94	24	129	62	8.8	0.5	70	0.5	4350	9:10	30.05	0.08643	11061.37	198.08	198.19	0.06524	3036.17	143.23	128.95
02/04/94	02/04/94	24	130	62	8.7	0.5	70	0.5	4350	8:45	30.1	0.08655	10990.40	196.81	197.25	0.06478	3046.82	143.73	129.40
02/05/94	02/05/94	10	144	59	8.8	0.6	62	0.6	3600	16:30	30.04	0.08717	11014.32	197.24	200.31	0.06315	3380.50	159.47	139.96
02/06/94	02/06/94	23	142	60	8.8	0.55	58	0.6	3600	7:45	30	0.08792	10966.69	196.39	200.71	0.06596	3166.94	149.39	131.38
02/07/94	02/07/94	5									30	0.08632	0.00	0.00	0.00	0.08632	0.00	0.00	0.00
02/08/94	02/08/94	0									30	0.08632	0.00	0.00	0.00	0.08632	0.00	0.00	0.00
02/09/94	02/09/94	0									30	0.08632	0.00	0.00	0.00	0.08339	0.00	0.00	0.00
02/10/94	02/10/94	9	140	62	8.8	0.5	70	0.5	3000	9:45	30	0.08630	11069.37	198.23	198.01	0.06618	3014.54	142.20	125.47

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SVE Flow Calculation

West Unit

03/23/94

Date	Date	Running Time	Exhaust Temp	System Vacum	Inlet Flow (5-1	Exhaust Flow (	Inlet Temp (40-	Exhaust Back	HC Conc in Ex	Time	Barametric P	Inlet Flow Densit	Air Velocity	ACFM	SCFM	Outlet Flow Densit	Air Velocity	ACFM	SCFM
Date	Date	Running Time	Exhaust Temp	System Vacum	Inlet Flow (5-1	Exhaust Flow (	Inlet Temp (40-	Exhaust Back	HC Conc in Ex	Time	Barametric P	Inlet Flow Densit	Air Velocity	ACFM	SCFM	Outlet Flow Densit	Air Velocity	ACFM	SCFM
08/03/93	08/03/93	18	134	60	6.8	0.65	60	0.52		08:30									
08/04/93	08/04/93	23	142	70	7.5	0.5	49	0.4		17:00	29.85	0.09099	9952.40	178.22	184.41	0.06383	3069.57	144.80	126.68
08/05/93	08/05/93	24	146	70	7.5	0.5	50.5	0.4		17:20	29.94	0.09097	9953.55	178.24	184.48	0.06361	3074.72	145.04	126.46
08/06/93	08/06/93	24	145	70	7.5	0.5	50	0.4		17:25	29.96	0.09110	9946.55	178.12	184.62	0.06375	3071.39	144.89	126.59
08/07/93	08/07/93	24	144	70	7.5	0.5	50	0.4		17:00	30.01	0.09124	9938.77	177.98	184.81	0.06398	3065.96	144.63	126.81
08/08/93	08/08/93	24	146	70	7.5	0.5	50	0.4		18:20	29.98	0.09116	9943.01	178.05	184.71	0.06370	3072.61	144.94	126.54
08/09/93	08/09/93	24	145	71	7.3	0.5	50	0.4		17:00	29.97	0.09131	9801.38	175.52	181.99	0.06377	3070.86	144.86	126.61
08/10/93	08/10/93	24	146	70	7.4	0.5	52	0.4		18:55	29.79	0.09031	9922.72	177.69	182.45	0.06328	3082.67	145.42	126.15
08/11/93	08/11/93	24	145	70	7.4	0.5	52	0.4		18:40	29.71	0.09011	9934.10	177.90	182.17	0.06321	3084.38	145.50	126.09
08/12/93	08/12/93	24	140	70	7.4	0.5	51	0.4			29.64	0.09010	9934.37	177.90	182.10	0.06359	3075.34	145.07	126.47
08/13/93	08/13/93	24	135	70	7.3	0.5	49	0.4		07:00	29.35	0.08969	9889.71	177.10	180.18	0.06346	3078.29	145.21	126.38
08/14/93	08/14/93	24	138	69	7.2	0.45	49	0.4		07:15	29.07	0.08878	9871.75	176.78	178.17	0.06254	2941.89	138.78	119.05
08/15/93	08/15/93	24	136	70	7.2	0.45	48	0.4		08:00	29.39	0.08998	9805.70	175.60	179.28	0.06346	2920.47	137.77	119.89
08/16/93	08/16/93	24	139	70	7.4	0.5	50	0.4		10:30	29.50	0.08991	9944.68	178.08	181.78	0.06338	3080.27	145.31	126.28
08/17/93	08/17/93	24	140	70	7.4	0.5	50	0.4		07:30	29.53	0.08998	9941.09	178.02	181.87	0.06333	3081.49	145.36	126.23
08/18/93	08/18/93	24	140	70	7.4	0.5	50	0.4	10000	07:42	29.21	0.08916	9986.56	178.83	180.75	0.06264	3098.54	146.17	125.57
08/19/93	08/19/93	24	142	68	7.4	0.5	50	0.4	10000	07:45	29.35	0.08913	9988.31	178.87	181.62	0.06273	3096.35	146.06	125.65
08/20/93	08/20/93	24	145	69	7.4	0.5	52	0.4	10000	07:30	29.49	0.08933	9976.91	178.66	181.57	0.06250	3101.98	146.33	125.85
08/21/93	08/21/93	22	140	69	7.8	0.55	50	0.45	10000	08:20	29.69	0.09022	10192.80	182.53	187.52	0.06370	3222.65	152.02	132.75
08/22/93	08/22/93	24	133	68	7.9	0.5	50	0.4	10000	07:45	29.80	0.09031	10252.55	183.60	189.32	0.06469	3048.90	143.83	127.55
08/23/93	08/23/93	20	130	66	8.2	0.55	48	0.4	10000	07:30	29.86	0.09044	10437.97	186.92	193.89	0.06516	3186.32	150.31	134.24
08/24/93	08/24/93	22	127	68	8.1	0.5	45	0.4	10000	07:30	29.87	0.09139	10320.13	184.81	192.90	0.06505	3040.45	143.43	128.80
08/25/93	08/25/93	24	131	68	8.1	0.55	48	0.5	10000	07:10	29.90	0.09091	10347.03	185.29	192.42	0.06467	3198.31	150.87	134.68
08/26/93	08/26/93	24	140	68	8	0.55	52	0.5	10000	11:15	29.91	0.09024	10321.15	184.83	190.54	0.06373	3221.74	151.98	133.70
08/27/93	08/27/93	21	146	66	8	0.6	54	0.5	10000	15:05	29.92	0.08953	10362.39	185.57	190.59	0.06311	3381.48	159.51	138.96
08/28/93	08/28/93	24	143	67	8	0.55	54	0.5	10000	08:00	29.88	0.08963	10356.66	185.46	190.26	0.06335	3231.46	152.44	133.30
08/29/93	08/29/93	24	140	68	8	0.5	53	0.5	10000	08:30	29.74	0.08962	10357.22	185.47	189.72	0.06335	3081.15	145.35	127.11
08/30/93	08/30/93	24	142	64	8.1	0.6	54	0.5	10000	10:50	29.69	0.08857	10483.20	187.73	191.36	0.06304	3383.50	159.61	138.91
08/31/93	08/31/93	24	138	70	8.2	0.55	52	0.5	10000	09:15	29.00	0.08827	10565.46	189.20	189.11	0.06202	3265.87	154.06	131.84
09/01/93	09/01/93	21	149	66	8	0.55	53	0.48		08:30	29.355	0.08826	10436.70	186.90	188.73	0.06158	3277.44	154.61	131.51
09/02/93	09/02/93	24	136	62	8.5	0.6	52	0.5		18:06	29.485	0.08800	10773.29	192.92	196.06	0.06322	3378.70	159.38	139.15
09/03/93	09/03/93	24	132	64	8.6	0.6	51	0.5		10:45	29.75	0.08924	10760.96	192.70	197.98	0.06419	3352.97	158.17	140.27
09/04/93	09/04/93	24	132	65	8.6	0.6	50	0.51	10000	09:00	29.94	0.09010	10709.55	191.78	198.68	0.06466	3340.75	157.59	140.65
09/05/93	09/05/93	24	133	65	8.6	0.59	51	0.5	10000	09:50	29.795	0.08955	10742.50	192.37	197.94	0.06423	3323.93	156.80	139.03
09/06/93	09/06/93	24	138	65	8.4	0.6	54	0.5		09:20	29.14	0.08734	10750.29	192.51	192.60	0.06224	3405.06	160.63	138.13
09/07/93	09/07/93	24	138	65	8.4	0.6	54	0.5	10000	13:20	29.38	0.08796	10712.45	191.83	193.50	0.06277	3390.62	159.95	138.67
09/08/93	09/08/93	24	129	67	8.6	0.6		0.5	10000	07:45	30.055	0.10065	10132.86	181.45	209.22	0.06571	3314.07	156.33	140.78
09/09/93	09/09/93	24	139	66	8.3	0.6	52	0.4	10000	19:30	29.8	0.08958	10551.81	188.96	194.08	0.06405	3356.75	158.35	139.02
09/10/93	09/10/93	24	138	66	8.3	0.56	54	0.4	10000	18:30	30.08	0.08995	10529.94	188.57	194.74	0.06477	3224.69	152.12	135.03
09/11/93	09/11/93	24	140	67	8.2	0.6	54	0.4	10000	14:45	29.75	0.08929	10504.95	188.12	192.14	0.06383	3362.46	158.62	138.79
09/12/93	09/12/93	24	138	66	8	0.55	53	0.4	10000	08:20	29.56	0.08878	10405.57	186.34	189.48	0.06362	3224.54	152.11	132.69
09/13/93	09/13/93	24	138	69	8	0.55	53	0.4	10000	11:00	29.89	0.09021	10323.31	184.87	190.08	0.06413	3211.82	151.51	133.64
09/14/93	09/14/93	24	142	69	8	0.6	56	0.45	10000	08:50	29.79	0.08942	10368.29	185.67	189.16	0.06348	3371.66	159.05	138.89
09/15/93	09/15/93	24	143	70	7.6	0.5	55	0.45	10000	08:44	29.7	0.08956	10098.35	180.84	184.04	0.06340	3079.81	145.28	126.28
09/16/93	09/16/93	24	145	70	7.2	0.5	56	0.4	10000	08:21	29.35	0.08848	9888.33	177.08	177.74	0.06220	3109.33	146.68	125.57
09/17/93	09/17/93	24	138	71	7.4	0.45	52	0.45	10000	08:30	29.875	0.09072	9900.28	177.29	182.56	0.06432	2900.86	136.84	120.64
09/18/93	09/18/93	24	142	70	7.4	0.5	54	0.4	10000	13:30	29.835	0.09008	9935.68	177.92	182.25	0.06246	3102.92	146.37	128.02
09/19/93	09/19/93	24	130	47	4	0.7	67	0.7	9200	07:59	29.4	0.08252	7632.24	136.67	134.55	0.06275	3662.80	172.79	151.94
09/20/93	09/20/93	24	122	46	3.8	0.65	61	0.7	9050	08:23	29.28	0.08297	7418.39	132.85	131.75	0.06334	3513.10	165.72	147.13
09/21/93	09/21/93	24	120	48	3.8	0.6	60	0.7	7000	08:10	29.37	0.08374	7384.52	132.24	131.80	0.06516	3327.86	156.99	140.28
09/22/93	09/22/93	24	126	70	8	0.5	54	0.4	10000	08:15	29.905	0.09026	10320.31	184.81	189.75	0.06570	3025.37	142.72	128.53
09/23/93	09/23/93	24	140	70	7.4	0.4	54	0.4	10000	08:00	29.87	0.09017	9930.72	177.83	182.37	0.06409	2739.76	129.24	113.54
09/24/93	09/24/93	24	140	72	7.2	0.4	54	0.4	10000	08:30	29.85	0.09049	9777.88	175.10	179.45	0.06405	2740.70	129.29	113.51
09/25/93	09/25/93	24	140	74	7	0.4	52	0.4	10000	07:20	29.79	0.09107	9610.44	172.10	176.71	0.06437	2733.95	128.97	113.00
09/26/93	09/26/93	24	138	75	7	0.4	50	0.3	10000	08:40	29.81	0.09167	9578.95	171.54	176.94	0.06282	2767.32	130.54	114.84
09/27/93	09/27/93	12	110	42	4	0.6	55	0.7	6800	08:00	30.155	0.08543	7500.75	134.32	138.79	0.06813	3254.62	153.53	143.33
09/28/93	09/28/93	24	160	62	6.4	0.6	70	0.4	10000	10:40	29.6	0.08530	9495.10	170.03	167.58	0.06145	3426.93	161.66	136.20
09/29/93	09/29/93	20	125	68	8.2	0.4	50	0.4	10000	07:10	29.67	0.08997	10464.97	187.40	192.40	0.06528	2714.65	128.06	114.61
09/30/93	09/30/93	24	132	70	7.5	0.4	48	0.4	10000	07:10	29.02	0.08902	10061.94	180.18	181.65	0.06306	2762.13	130.30	112.72
10/01/93	10/01/93	24	162	68	7.4	0.5	68	0.4	10000	08:00	29.23	0.08580	10180.11	182.30	178.10	0.06003	3165.08	149.31	123.82
10/02/93	10/02/93	16	162	66	8	0.5	68	0.5	10000	09:15	29.62	0.08641	10547.41	188.88	186.98	0.06097	3140.64	148.15	124.50
10/03/93	10/03/93	12	147	69	9	0.5	62	0.475	10000	08:09	30.05	0.08906	11019.97	197.34	200.48	0.06341	3079.51	145.27	126.91
10/04/93	10/04/93	20	154	71	9	0.5	63	0.475	10000	07:31	30	0.08913	11015.31	197.26	199.68	0.06247	3102.61	146.36	126.20
10/05/93	10/05/93	14	151	67	9.1	0.5	61	0.5	10000	09:15	29.62	0.08776	11162.48	199.89	200.55	0.06416	3061.50	144.42	123.55
10/06/93	10/06/93	2								08:45	29.54	0.08499	0.00	0.00	0.00	0.08499	0.00	0.00	0.00
10/07/93	10/07/93	0								08:30	29.5	0.08488	0.00	0.00	0.00	0.08254	0.00	0.00	0.00
10/08/93	10/08/93	15	154	65	9.5	0.6	62	0.4	10000	08:30	29.4	0.08666	11477.25	205.53	204.28	0.06118	3434.47	162.01	136.90
10/09/93	10/09/93	24	140	68	9	0.5	59	0.5	10000	08:15	29.5	0.08798	11087.11	198.54	199.15	0.06238	3104.95	146.47	127.08
10/10/93	10/10/93	24	160	64	9.5	0.5	66	0.6	10000	08:30	29.8	0.08682	11466.51	205.34	205.29	0.06144	3128.54	147.58	125.18
10/11/93	10/11/93	24	140	66	9.5	0.5	58	0.5	10000	08:00	29.5	0.08777	11404.28	204.22	205.24	0.06238	3104.95	146.47	127.08
10/12/93	10/12/93	24	140	66	9.5	0.5	58	0.6	10000	08:15	29.2	0.08701	11454.40	205.12	204.05	0.06217	3110.26	146.72	126.01
10/13/93	10/13/93	24	150	65	9.5	0.6	60	0.5	10000	08:10	29.91	0.08829	11370.72	203.62	206.69	0.06225	3404.94	160.62	138.98
10/14/93	10/14/93	24	162	64	9.5	0.6	62	0.6	10000	08:15	29.39	0.08645	11491.30	205.78	204.46	0.06037	3457.38	163.09	135.99
10/15/93	10/15/93	24	142	66	9.5	0.5	56	0.5		08:20	29.87	0.08906	11321.43	202.74	207.11	0.06343	3079.05	145.25	127.18

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Date	Date	Running Time	Exhaust Temp	System Vacum	Inlet Flow (5-1(	Exhaust Flow (	Inlet Temp (40-	Exhaust Back	HC Conc in Ex	Time	Barametric P	Inlet Flow Densit	Air Velocity	ACFM	SCFM	Outlet Flow Densit	Air Velocity	ACFM	SCFM
10/16/93	10/16/93	24	132	64	9.5	0.5	56	0.5	10000	08:30	29.89	0.08874	11342.20	203.11	207.63	0.06455	3052.31	143.99	128.29
10/17/93	10/17/93	24	134	64	9.5	0.5	56	0.5	10000	08:15	29.39	0.08746	11425.07	204.59	205.64	0.06322	3084.29	145.49	127.04
10/18/93	10/18/93	24	130	65	9.5	0.5	56	0.5	10000	08:10	29.39	0.08764	11412.77	204.37	205.42	0.06365	3073.89	145.00	127.47
10/19/93	10/19/93	24	130	64	9.8	0.5	56	0.5	10000	08:20	29.89	0.08874	11519.90	206.29	210.88	0.06477	3047.15	143.74	128.51
10/20/93	10/20/93	24	130	64	9.8	0.5	55	0.5	10000	08:10	29.59	0.08814	11558.96	206.99	209.88	0.06409	3063.11	144.50	127.89
10/21/93	10/21/93	24	130	64	9.8	0.5	54	0.5	10000	08:20	29.68	0.08854	11532.61	206.52	210.44	0.06430	3058.30	144.27	128.07
10/22/93	10/22/93	24	124	64	9.8	0.5	52	0.5	10000	09:10	29.42	0.08822	11553.91	206.90	209.80	0.06437	3056.60	144.19	128.18
10/23/93	10/23/93	24	124	64	10	0.5	50	0.5	10000	08:45	29.69	0.08926	11602.59	207.77	213.45	0.06498	3042.18	143.51	128.75
10/24/93	10/24/93	24	150	64	9.8	0.6	62	0.5	10000	10:00	29.39	0.08645	11671.33	209.00	207.66	0.06156	3423.87	161.51	137.33
10/25/93	10/25/93	24	135	64	10	0.5	58	0.5	10000	08:10	30.04	0.08878	11634.19	208.34	213.21	0.06456	3052.12	143.98	128.28
10/26/93	10/26/93	24	125	64	10	0.5	52	0.5	10000	08:10	30.05	0.08984	11564.95	207.10	214.50	0.06568	3025.84	142.74	129.39
10/27/93	10/27/93	24	148	62	10	0.6	61	0.5	10000	08:20	30.04	0.08789	11692.60	209.39	213.05	0.06318	3379.76	159.43	139.01
10/28/93	10/28/93	12	140	62	10	0.6	62	0.5	10000	08:15	30.01	0.08765	11708.90	209.68	212.73	0.06395	3359.19	158.46	139.87
10/29/93	10/29/93	12	138	60	10.5	0.6	60	0.5	10000	08:20	29.94	0.08743	12012.82	215.12	218.58	0.06401	3357.64	158.39	139.94
10/30/93	10/30/93	24	142	60	10.5	0.5	62	0.5	10000	09:20	29.78	0.08669	12064.02	216.04	217.50	0.06323	3083.87	145.48	127.00
10/31/93	10/31/93	24	139	60	10.5	0.5	61	0.5	10000	08:30	29.76	0.08681	12055.99	215.89	217.62	0.06351	3077.24	145.16	127.27
11/01/93	11/01/93	16	136	60	10	0.5	60	0.5	10000	08:10	29.74	0.08692	11757.58	210.55	212.50	0.06378	3070.60	144.85	127.55
11/02/93	11/02/93	24	136	65	9.5	0.5	58	0.5	10000	08:20	29.86	0.08851	11357.02	203.38	206.89	0.06405	3064.20	144.55	127.80
11/03/93	11/03/93	24	138	65	9.8	0.5	58	0.5	10000	09:30	30.04	0.08897	11505.09	206.03	210.85	0.06423	3059.80	144.34	127.96
11/04/93	11/04/93	19	129	65	9.8	0.5	55	0.5	10000	09:25	29.95	0.08925	11486.59	205.70	211.10	0.06478	3046.78	143.73	128.97
11/05/93	11/05/93	23	140	65	9.8	0.5	58	0.55	10000	09:30	29.97	0.08879	11516.68	206.24	210.57	0.06386	3068.62	144.76	127.60
11/06/93	11/06/93	24	148	64	9.8	0.6	62	0.5	10000	12:00	29.84	0.08759	11595.06	207.64	209.46	0.06274	3391.46	159.99	138.56
11/07/93	11/07/93	24	138	65	9.8	0.5	60	0.5	10000	09:35	29.89	0.08824	11552.19	206.87	209.84	0.06390	3067.74	144.71	127.65
11/08/93	11/08/93	24	136	65	9.8	0.5	62	0.5	10000	08:20	29.89	0.08790	11574.39	207.27	209.44	0.06412	3062.61	144.47	127.86
11/09/93	11/09/93	24	140	64	9.6	0.5	62	0.5	10000	08:00	29.34	0.08632	11560.10	207.01	205.33	0.06247	3102.56	146.36	126.30
11/10/93	11/10/93	24	146	64	9.5	0.5	64	0.5	10000	09:40	29.55	0.08652	11486.37	205.69	204.70	0.06231	3106.54	146.54	126.10
11/11/93	11/11/93	24	144	62	9.7	0.5	64	0.5	10000	09:35	29.34	0.08562	11667.62	208.94	206.45	0.06206	3112.89	146.84	125.88
11/12/93	11/12/93	24	160	62	9.5	0.5	66	0.5	10000	10:30	29.42	0.08550	11555.09	206.92	204.24	0.06063	3149.40	148.57	124.41
11/13/93	11/13/93	24	138	64	9.7	0.5	60	0.5	10000	09:20	29.32	0.08660	11601.28	207.75	206.72	0.06264	3098.48	146.16	126.47
11/14/93	11/14/93	24	136	64	9.8	0.5	60	0.5	10000	10:15	29.42	0.08686	11643.83	208.51	208.18	0.06307	3087.84	145.66	126.89
11/15/93	11/15/93	24	134	65	9.8	0.5	60	0.5	10000	08:20	29.84	0.08812	11560.53	207.02	209.64	0.06422	3060.12	144.35	127.97
11/16/93	11/16/93	24	130	64	9.8	0.5	58	0.5	10000	15:30	29.89	0.08840	11542.20	206.69	210.47	0.06477	3047.15	143.74	128.51
11/17/93	11/17/93	24	134	65	9.8	0.5	60	0.5	10000	08:20	29.98	0.08847	11537.23	206.60	210.20	0.06453	3052.71	144.01	128.26
11/18/93	11/18/93	24	136	66	9.8	0.5	60	0.5	10000	08:05	29.73	0.08802	11566.63	207.13	208.98	0.06376	3071.13	144.87	127.53
11/19/93	11/19/93	24	136	66	9.9	0.5	60	0.5	10000	15:30	29.92	0.08851	11593.69	207.61	210.81	0.06418	3061.02	144.40	127.92
11/20/93	11/20/93	24	136	66	9.9	0.5	60	0.5	10000	10:40	30.21	0.08924	11545.64	206.75	211.97	0.06483	3045.78	143.68	128.52
11/21/93	11/21/93	24	138	64	9.8	0.5	66	0.5	10000	10:30	29.58	0.08627	11683.45	209.22	207.63	0.06321	3084.35	145.50	127.01
11/22/93	11/22/93	24	154	62	9.6	0.5	70	0.5	10000	08:20	29.72	0.08560	11608.70	207.88	205.71	0.06187	3117.70	147.07	125.63
11/23/93	11/23/93	24	128	66	9.6	0.5	56	0.5	10000	08:20	29.41	0.08788	11457.01	205.17	206.36	0.06391	3067.59	144.71	127.73
11/24/93	11/24/93	24	142	65	9.8	0.5	62	0.5	10000	14:25	29.96	0.08808	11562.72	207.06	209.72	0.06363	3074.26	145.02	127.37
11/25/93	11/25/93	24	142	65	9.9	0.5	62	0.5	10000	15:30	29.91	0.08795	11629.94	208.26	210.59	0.06352	3076.92	145.15	127.26
11/26/93	11/26/93	24	142	64	9.9	0.5	62	0.5	10000	16:38	29.86	0.08764	11650.70	208.64	210.61	0.06341	3079.59	145.27	127.16
11/27/93	11/27/93	24	142	64	10	0.5	61	0.5	10000	10:30	29.92	0.08796	11688.03	209.30	212.12	0.06354	3076.39	145.12	127.28
11/28/93	11/28/93	24	150	62	9.8	0.5	62	0.5	10000	11:20	29.72	0.08691	11640.14	208.45	209.43	0.06228	3107.53	146.59	126.04
11/29/93	11/29/93	24	149	62	9.9	0.55	62	0.5	10000	08:00	29.4	0.08610	11754.37	210.49	209.21	0.06168	3274.84	154.48	131.61
11/30/93	11/30/93	24	149	62	9.9	0.55	62	0.5	10000	08:00	29.4	0.08610	11754.37	210.49	209.21	0.06168	3274.84	154.48	131.61
12/01/93	12/01/93	24	149	62	9.9	0.55	62	0.5	10000	08:00	29.4	0.08610	11754.37	210.49	209.21	0.06168	3274.84	154.48	131.61
12/02/93	12/02/93	24	148	62	10	0.6	62	0.5	10000	08:20	29.12	0.08539	11862.60	212.43	209.13	0.06117	3434.64	162.02	136.94
12/03/93	12/03/93	24	132	64	9.8	0.5	54	0.5	10000	08:25	29.52	0.08813	11559.53	207.00	209.80	0.06372	3072.06	144.92	127.52
12/04/93	12/04/93	24	133	64	9.8	0.5	60	0.5	10000	09:20	29.62	0.08737	11609.86	207.90	208.99	0.06384	3069.28	144.79	127.62
12/05/93	12/05/93	24	132	64	9.9	0.5	62	0.5	10000	10:20	29.32	0.08627	11742.79	210.28	208.44	0.06327	3082.90	145.43	127.11
12/06/93	12/06/93	24	138	64	9.8	0.5	70	0.5	10000	08:10	29	0.08417	11828.27	211.82	204.53	0.06171	3121.83	147.27	126.03
12/07/93	12/07/93	24	132	62	9.7	0.5	60	0.55	11000	11:30	28.35	0.08376	11796.53	211.25	203.24	0.06088	3142.99	148.26	125.30
12/08/93	12/08/93	24	125	62	9.7	0.5	57	0.55	10000	11:00	29.01	0.08594	11646.25	208.56	206.52	0.06310	3087.16	145.63	127.44
12/09/93	12/09/93	20	127	62	9.8	0.5	57	0.55	10000		29.2	0.08642	11673.14	209.04	208.35	0.06331	3081.95	145.38	127.63
12/10/93	12/10/93	24	128	62	9.8	0.5	56	0.55	10000	16:30	29.5	0.08736	11610.37	207.91	209.76	0.06411	3062.74	144.48	127.91
12/11/93	12/11/93	17	142	60	9.9	0.5	62	0.5	10000	09:40	29.75	0.08662	11719.41	209.87	211.07	0.06317	3085.48	145.55	126.93
12/12/93	12/12/93	24	150	60	9.9	0.6	66	0.5	10000	16:30	29.42	0.08513	11821.46	211.69	208.95	0.06162	3422.06	161.43	137.39
12/13/93	12/13/93	24	140	60	9.9	0.5	61	0.5	10000	12:40	29.49	0.08612	11752.99	210.47	210.23	0.06505	3040.49	143.43	124.40
12/14/93	12/14/93	24								09:35	29.58	0.08511	0.00	0.00	0.00	0.08511	0.00	0.00	0.00
12/15/93	12/15/93	2								12:00	29.58	0.08511	0.00	0.00	0.00	0.08218	0.00	0.00	0.00
12/16/93	12/16/93	4	142	60	9.8	0.6	60	0.5	11000	12:15	29.56	0.08647	11670.21	208.98	209.65	0.06275	3391.20	159.97	138.62
12/17/93	12/17/93	24	136	60	10	0.5	60	0.5	10000		29.5	0.08631	11799.12	211.29	211.53	0.06325	3083.51	145.46	127.05
12/18/93	12/18/93	24	134	60	10	0.5	60	0.5	10000		29.3	0.08580	11834.06	211.92	210.72	0.06302	3089.19	145.73	126.85
12/19/93	12/19/93	24	132	60	10	0.5	60	0.5	10000	13:50	29.02	0.08509	11883.52	212.80	209.58	0.06260	3099.37	146.21	126.48
12/20/93	12/20/93	24	135	60	10	0.5	60	0.5	10000		29.2	0.08555	11851.66	212.23	210.31	0.06269	3097.27	146.11	126.53
12/21/93	12/21/93	24	138	60	10	0.5	60	0.5	10000	09:30	29.35	0.08593	11825.30	211.76	210.92	0.06271	3096.84	146.09	126.53
12/22/93	12/22/93	24	138	60	10	0.5	60	0.5	10000		29.3	0.08580	11834.06	211.92	210.72	0.06260	3099.58	146.22	126.43
12/23/93	12/23/93	24	138	60	10	0.5	60	0.5	10000	10:20	29.32	0.08586	11830.56	211.86	210.80	0.06264	3098.48	146.16	126.47
12/24/93	12/24/93	24	140	60	10	0.5	60	0.5	10000		29.5	0.08631	11799.12	211.29	211.53	0.06283	3093.84	145.95	126.63
12/25/93	12/25/93	24	140	60	10	0.5	60	0.5	10000		29.5	0.08631	11799.12	211.29	211.53	0.06283	3093.84	145.95	126.63
12/26/93	12/26/93	24	140	60	10	0.5	60	0.5	10000		29.5	0.08631	11799.12	211.29	211.53	0.06283	3093.84	145.95	126.63
12/27/93	12/27/93	24	140	60	10	0.5	60	0.5	10000		29.5	0.08631	11799.12	211.29	211.53	0.06283	3093.84	145.95	126.63
12/28/93	12/28/93	24	140	60	10	0.5	60	0.5	10000	12:00	29.76	0.08698	11754.14	210.49	212.58	0.06340	3079.81	145.28	127.17
12/29/93	12/29/93	24	140	60	10	0.5	60	0.5	10000		29.5	0.08631	11799.12	211.29	211.53	0.06283	3093.84	145.95	126.63
12/30/93	12/30/93	24	140	60	10	0.5	60	0.5	10000		29.5	0.08631	11799.12	211.29	211.53	0.06283	3093.84	145.95	126.63
12/31/93	12/31/93	24	140	60	10	0.5	60	0.5	10000		29.5	0.08631	11799.12	211.29	211.53	0.06283	3093.84	145.95	126.63

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SVE Flow Calculation

West Unit

03/23/94

Date	Date	Running Time	Exhaust Temp	System Vacum	Inlet Flow (5-1	Exhaust Flow (	Inlet Temp (40-	Exhaust Back	HC Conc In Ex	Time	Barametric P	Inlet Flow Densit	Air Velocity	ACFM	SCFM	Outlet Flow Densit	Air Velocity	ACFM	SCFM
01/01/94	01/01/94	24	140	60	10	0.5	60	0.5	10000		29.5	0.08631	11799.12	211.29	211.53	0.06283	3093.84	145.95	126.63
01/02/94	01/02/94	24	140	60	10	0.5	60	0.5	10000		29.5	0.08631	11799.12	211.29	211.53	0.06283	3093.84	145.95	126.63
01/03/94	01/03/94	24	140	60	10	0.5	60	0.5	10000		29.5	0.08631	11799.12	211.29	211.53	0.06283	3093.84	145.95	126.63
01/04/94	01/04/94	24	140	60	10	0.5	60	0.5	10000		29.5	0.08631	11799.12	211.29	211.53	0.06283	3093.84	145.95	126.63
01/05/94	01/05/94	24	140	60	10	0.5	60	0.5	10000		29.5	0.08631	11799.12	211.29	211.53	0.06507	3039.98	143.40	124.42
01/06/94	01/06/94	6									29.9	0.08603	0.00	0.00	0.00	0.08603	0.00	0.00	0.00
01/07/94	01/07/94	0									29.9	0.08603	0.00	0.00	0.00	0.08603	0.00	0.00	0.00
01/08/94	01/08/94	0									29.9	0.08603	0.00	0.00	0.00	0.08251	0.00	0.00	0.00
01/09/94	01/09/94	15	134	62	10.1	0.5	60	0.6	7800	14:00	29.9	0.08771	11763.46	210.65	213.75	0.06435	3056.94	144.20	128.10
01/10/94	01/10/94	24	150	62	10	0.6	70	0.5	10000	8:45	29.9	0.08605	11817.09	211.62	210.68	0.06267	3393.51	160.08	138.47
01/11/94	01/11/94	24	141	62	10	0.65	68	0.5	10000		29.95	0.08650	11786.23	211.06	211.27	0.06371	3502.89	165.24	145.32
01/12/94	01/12/94	24	141	62	10	0.65	68	0.5	10000		29.95	0.08650	11786.23	211.06	211.27	0.06371	3502.89	165.24	145.32
01/13/94	01/13/94	24	132	62	9.9	0.7	66	0.5	10000	09:20	30.02	0.08701	11693.06	209.39	210.89	0.06484	3603.44	169.99	152.11
01/14/94	01/14/94	24	132	62	9.9	0.7	66	0.5	10000	09:50	29.95	0.08683	11704.92	209.61	210.61	0.06468	3607.80	170.19	151.94
01/15/94	01/15/94	24	133	62	9.9	0.7	67	0.5	10000	08:40	30.02	0.08684	11704.17	209.59	210.69	0.06473	3606.49	170.13	151.99
01/16/94	01/16/94	24	133	62	9.9	0.7	67	0.5	10000	08:45	30.08	0.08699	11694.03	209.41	210.93	0.06486	3602.76	169.95	152.13
01/17/94	01/17/94	24	134	62	10	0.8	68	0.5	10000	10:15	30.01	0.08665	11776.00	210.88	211.51	0.06460	3859.41	182.06	162.32
01/18/94	01/18/94	24	133	62	10	0.8	68	0.5	10000	08:45	29.95	0.08650	11786.23	211.06	211.27	0.06457	3860.16	182.09	162.30
01/19/94	01/19/94	24	134	62	10	0.7	67	0.5	10000	10:35	29.95	0.08667	11775.06	210.86	211.47	0.06447	3613.89	170.48	151.69
01/20/94	01/20/94	24	134	62	10	0.8	68	0.5	10000	10:00	29.89	0.08635	11796.49	211.25	211.03	0.06433	3867.42	182.44	162.00
01/21/94	01/21/94	24	134	62	10	0.8	68	0.5	10000	09:40	29.96	0.08653	11784.52	211.03	211.31	0.06449	3862.74	182.22	162.19
01/22/94	01/22/94	24	133	62	9.9	0.6	67	0.5	10000	10:20	30.01	0.08682	11705.87	209.62	210.65	0.06471	3339.53	157.54	140.69
01/23/94	01/23/94	24	133	62	10	0.7	68	0.5	10000	9:20	29.98	0.08658	11781.11	210.97	211.39	0.06464	3608.98	170.25	151.89
01/24/94	01/24/94	24	133	62	10	0.7	67	0.5	10000	8:40	29.95	0.08667	11775.06	210.86	211.47	0.06457	3610.85	170.33	151.82
01/25/94	01/25/94	24	133	62	10	0.6	68	0.5	10000	11:00	29.85	0.08625	11803.34	211.37	210.87	0.06435	3348.79	157.97	140.33
01/26/94	01/26/94	24	133	62	10	0.6	68	0.5	10000	8:45	29.52	0.08542	11860.35	212.39	209.55	0.06361	3368.12	158.88	139.58
01/27/94	01/27/94	24	134	62	9.9	0.6	68	0.5	10000	8:40	29.59	0.08560	11788.80	211.11	208.78	0.06366	3366.82	158.82	139.62
01/28/94	01/28/94	24	134	62	9.9	0.6	68	0.5	10000	8:50	29.85	0.08625	11744.18	210.31	209.82	0.06424	3351.61	158.11	140.21
01/29/94	01/29/94	24	137	62	10	0.7	70	0.5	10000	10:50	29.8	0.08580	11834.28	211.92	210.28	0.06381	3632.43	171.35	150.94
01/30/94	01/30/94	24	138	62	10	0.7	72	0.5	10000	9:20	29.87	0.08565	11844.53	212.11	210.16	0.06386	3631.06	171.29	150.98
01/31/94	01/31/94	24	141	62	10	0.7	74	0.5	10000	8:20	29.95	0.08553	11853.01	212.26	210.08	0.06371	3635.12	171.48	150.80
02/01/94	02/01/94	24	141	62	10	0.7	74	0.5	10000	8:15	29.95	0.08553	11853.01	212.26	210.08	0.06371	3635.12	171.48	150.80
02/02/94	02/02/94	24	140	62	10	0.7	72	0.5	10000	8:40	29.98	0.08593	11825.65	211.77	210.60	0.06389	3630.21	171.25	151.00
02/03/94	02/03/94	24	138	62	10	0.6	70	0.5	10000	9:10	30.05	0.08643	11791.46	211.16	211.27	0.06426	3351.27	158.09	140.19
02/04/94	02/04/94	24	138	62	10	0.6	71	0.5	10000	8:45	30.1	0.08639	11794.06	211.20	211.27	0.06392	3360.17	158.51	140.80
02/05/94	02/05/94	10	137	64	10	0.6	66	0.6	10000	16:30	30.04	0.08743	11723.69	209.94	211.59	0.06411	3354.93	158.26	140.53
02/06/94	02/06/94	23	145	62	10	0.6	70	0.55	10000	7:45	30	0.08630	11799.99	211.31	211.07	0.06563	3315.99	156.43	136.88
02/07/94	02/07/94	5									30	0.08632	0.00	0.00	0.00	0.08632	0.00	0.00	0.00
02/08/94	02/08/94	0									30	0.08632	0.00	0.00	0.00	0.08632	0.00	0.00	0.00
02/09/94	02/09/94	0									30	0.08632	0.00	0.00	0.00	0.08339	0.00	0.00	0.00
02/10/94	02/10/94	16	140	62	10	0.6	68	0.5	10000	9:45	30	0.08663	11777.70	210.91	211.47	0.06618	3302.26	155.78	137.45

APPENDIX C.4

Air Permeability Calculations and Modeling

RADIAN CORPORATION

CALCULATION SHEET

CALC. NO.

SIGNATURE MA Robbins DATE 12/31/93 CHECKED JA Rehage DATE 1/25/95

PROJECT GALENA TS JOB NO.

SUBJECT Calculation of air permeability coef. using transient pressure distribution data SHEET 1 OF 5 SHEETS

From: "A practical Approach to the Design, Operation, and Monitoring of In Situ Soil-Venting Systems." P.C. Johnson, C.C. Stanley, M.W. Kemblowski, D.L. Byers, and J.D. Colthart, GWMR, Spring 1990.

Procedure:

Flow rate and transient pressure distribution data are used to estimate the soil permeability to vapor flow. The expected change in the subsurface pressure distribution with time $P'(r,t)$ is predicted by:

$$P' = \frac{Q}{4\pi m (k/\mu)} \int_{\frac{r^2 \varepsilon \mu}{4 k P_{atm} t}}^{\infty} \frac{e^{-x}}{x}\, dx \qquad (1)$$

For $(r^2 \varepsilon \mu / 4 k P_{atm}\, t) < 0.1$ this equation can be approximated by:

$$P' = \frac{Q}{4\pi m (k/\mu)} \left[-0.5772 - \ln\left(\frac{r^2 \varepsilon \mu}{4\pi k P_{atm}} \right) + \ln(t) \right] \qquad (2)$$

Equation 2 predicts a plot of P'-vs-$\ln(t)$ should be a straight line with slope A and y-intercept B equal to:

$$A = \frac{Q}{4\pi m (k/\mu)}$$

$$B = \frac{Q}{4\pi m (k/\mu)} \left[-0.5772 - \ln\left(\frac{r^2 \varepsilon \mu}{4 k P_{atm}} \right) \right.$$

CALCULATION SHEET

CALC. NO.

SIGNATURE MA Robbins DATE 12/31/93 CHECKED DATE

PROJECT GALENA TS JOB NO.

SUBJECT Calculation of air permeability coef using Transient pressure distribution data SHEET 2 OF 5 SHEETS

where

P' = "guage" pressure measure at distance r and time t

m : stratum thickness

r = radial distance from vapor extraction well

k = soil permeability to air flow

μ = viscocity of air = 1.8×10^{-4} g/cm-s

ϵ = air-filled solid void fraction

t = time

Q = volumetric vapor flow rate from extraction well

P_{atm} = ambient atmospheric pressure = 1.0 atm = 1.013×10^{6} g/cm-s^2

The permeability to air flow can be calculated one of two ways. First, if Q and m are known, the calculated slope A is used.

$$k = \frac{Q\mu}{4 \textcircled{A} \pi m}$$

If Q or m is not known the both A and B are used

$$k = \frac{r^2 \epsilon \mu}{4 P_{atm}} \exp\left(\frac{B}{A} + 0.5772\right)$$

Since both Q and m ~~are~~ have been measured for the Galena project the first method can be used.

RADIAN
CORPORATION

CALCULATION SHEET

CALC. NO.

SIGNATURE MA Robbins DATE 12/31/93 CHECKED DATE

PROJECT Galena TS JOB NO.

SUBJECT calculation of air permeability coef using transient pressure distribution data. SHEET 3 OF 5 SHEETS

Example problem:

EQUATION: $K = \frac{Q\mu}{4\pi m A}$

Q = 137 scfm

μ = 1.8×10^{-4} g/cm-s

m : 21.5 ft

Slope A (See attached chart) = 0.782 (point V12)

$$K = \frac{137 \frac{ft^3}{min} \cdot \frac{(12 \cdot 2.54)^3 cm^3}{ft^3} , \frac{1 min}{60 \cdot sec} \cdot 1.8 \times 10^{-4}\ g/cm\text{-}s}{4(3.1416)(21.5\ ft \cdot 12 \cdot 2.54)cm\left(.782\ in\text{-}H_2O \cdot 2482.8\ \frac{g/cm\text{-}s}{in\text{-}H_2O}\right)}$$

$$\boxed{K = \frac{11.64}{8{,}235(1941.6)} = 7.28 \times 10^{-7}\ cm^2 = 72.8\ Darcy's}$$

See Attached spread sheet calculation to validate

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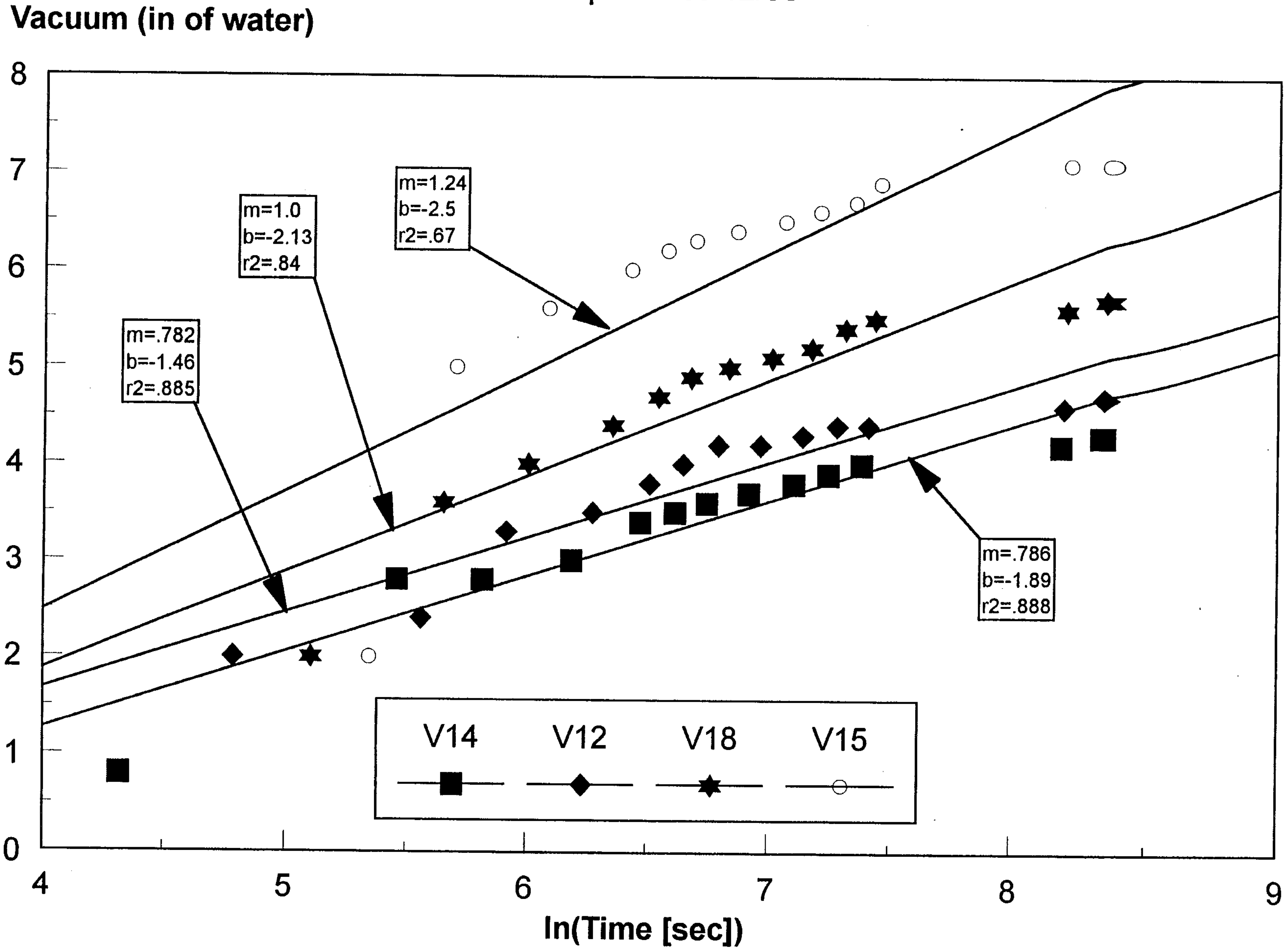
East Unit

Deep Probes 12/93



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Calculation of Air Permeablity Coefficient
Data gather on 12/10/93

East Unit

Q(cfm)	137
u(g/cm-s)	1.8E-04
M(ft)	21.5

EQUATION:

$$K = \frac{Q\mu}{4A\ piM}$$

where,

Q= flow from SVE well= 137 cfm

μ = viscocity of air = .00018 poise

A = slope of p vs ln(t) curve

M = stratum thickness = 21.5 ft

Point	Slope , A	K (cm2)	Darcy's
V14d	0.786	7.24E-07	72.42016
V12d	0.782	7.28E-07	72.7906
V18d	1	5.69E-07	56.92225
V15d	1.24	4.59E-07	45.90504
V14s	0.041	1.39E-05	1388.348
V12s	0.057	9.99E-06	998.636
V18s	0.11	5.17E-06	517.475
V15s	0.617	9.23E-07	92.25648

Calculation of Air Permeablity Coefficient
Data gather on 12/10/93

West Unit

Q(cfm)	127
u(g/cm-s)	1.8E-04
M(ft)	21.5

EQUATION:

$$K = \frac{Q\mu}{4A\ piM}$$

where,

Q= flow from SVE well= 137 cfm

μ = viscocity of air = .00018 poise

A = slope of p vs ln(t) curve

M = stratum thickness = 21.5 ft

Point	Slope , A	K (cm2)	Darcy's
V9d	0.019	3.00E-05	2995.908
V7d	0.49	1.16E-06	116.1679
V4d	0.42	1.36E-06	135.5292
V1d	0.5	1.14E-06	113.8445
V9s	0.283	2.01E-06	201.1387
V7s	0.377	1.51E-06	150.9874
V4s	0.328	1.74E-06	173.5434
V1s	0.371	1.53E-06	153.4292

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CALCULATION SHEET

CALC. NO.

SIGNATURE MA Robbins DATE 10/4/93 CHECKED J. Rehage DATE 1/25/95

PROJECT GALENA II JOB NO.

SUBJECT 1993 Radius of Influence Calc. SHEET 1 OF 4 SHEETS

Assumption: steady state radial flow, & homogeneous system

BASE EQUATION: (Johnson, et. al, 1990)

$$P_r^2 - P_w^2 = (P_{atm}^2 - P_w^2)\,\frac{\ln(r/R_w)}{\ln(R_I/R_w)}$$

Where

P_r = Pressure at a radial point at distance r, from the well
P_w = Pressure at the well
P_{atm} = Atmospheric pressure
r = Distance to observation (cm)
R_w = Radius of Well (cm)
R_I = Radius of Influence (cm)

Rearranging to solve for R_I:

$$\frac{(P_r^2 - P_w^2)}{(P_{atm}^2 - P_w^2)} = \frac{\ln(r/R_w)}{\ln(R_I/R_w)}$$

$$\exp\left[\frac{P_r^2 - P_w^2}{P_{atm}^2 - P_w^2}\right] = \frac{r/\cancel{R_w}}{R_I/\cancel{R_w}}$$

$$R_I = r \cdot \exp\left[\frac{P_{atm}^2 - P_w^2}{P_r^2 - P_w^2}\right]$$

DATA:

See ATTACHED FOR DATA FROM FIRST 1993 Air permeability ~~test~~.

2 of 4

Results of Air Permeability Test for West Unit (02-Aug-93)

Ti	ln(Ti)	V2-P	V1-P	V10-P	V7	V8
1	0	8.5	1	0.1		
4	1.386294	10.5	1.1	0.1		
7.5	2.014903	10.65	1.25	0.1		
11	2.397895	10.75	1.25	0.1		
16	2.772589	11.25	1.5	0.1	2.7	2.5
22	3.091042	11.25	1.5	0.1	3	2.6
28	3.332205	11.35	1.5	0.1	3.2	2.7
33	3.496508	11.5	1.5	0.1	3.25	2.8
45	3.806662	11.5	1.5	0.15	3.3	2.8
84	4.430817	11.5	1.5	0.2	3.3	2.8
145	4.976734	11.75	1.6	0.15	3.3	2.8
165	5.105945	11.75	1.6	0.15	3.3	2.8
240	5.480639	11.75	1.6	0.15	3.3	2.8
Radius from E1 (CM)		338.4				

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PROJECT Galena TS JOB NO.

SUBJECT 1993 Radius of Influence Calcs. SHEET 3 OF 4 SHEETS

Selecting V2 as point of Interest and assuming that steady - state conditions were reached by 240 minutes.

The radius of influence for the West SVE well (E1) based on data collected at V2 is:

$$R_I(V2) = r_{(V2)} \cdot \exp\left[\frac{P_{atm}^2 - P_{well}^2}{P_{r(V2)}^2 - P_{well}^2}\right]$$

$r_{(V2)} = \underline{308.4 \text{ cm}}$

$$P_{r}(V2) = P_{atm} \cdot 11.75 \text{ in-H}_2\text{O} = 1013000 \frac{g}{cm\text{-}sec^2} - 29\,230 \frac{g}{cm\text{-}sec^2}$$

$$= \underline{983,766} \frac{g}{cm\text{-}sec^2}$$

$$P_{well} = 1013000 \frac{g}{cm\text{-}sec^2} - 3.4 \text{ in-Hg} = 1013000 \frac{g}{cm\text{-}sec^2} - 115,041$$

$$= \underline{897,959} \frac{g}{cm\text{-}sec^2}$$

$$P_{atm} = \underline{1013000} \frac{g}{cm\text{-}sec^2}$$

$$R_I(V2) = 308.4 \text{ cm} * \exp\left[\frac{(1013000)^2 - (897,959)^2}{(983\,766)^2 - (897,959)^2}\right]$$

$$= 308.4 \text{ cm} * 3.902$$

$$= 1203.4 \text{ cm} = 39.5 \text{ FT}$$

SEE ATTACHED FOR REST OF CALCULATIONS

Monitoring Point ID:	**V2**	**V1**	**V10**	**V7**	**V8**	**Average**
Patm (g/cm-sec2)=	1013000	1013000	1013000	1013000	1013000	
Pwell (in_Hg) =	3.4	3.4	3.4	3.4	3.4	
Pr (in_H2O)=	11.75	1.6	0.15	3.3	2.8	
Rwell (cm)=	0.167	0.167	0.167	0.167	0.167	
Rr (cm) =	243.84	411.48	1828.8	1021.08	1143	
Ri (cm)=	951.229	1161.821	4988.367	3011.117	3326.658	1388.011
Ri (ft) =	**31.208**	**38.117**	**163.660**	**98.790**	**109.142**	**88.184**

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CALCULATION SHEET

CALC. NO.

SIGNATURE MA Robbins DATE 5/2/94 CHECKED JA. Rebage DATE

PROJECT Galena TS JOB NO.

SUBJECT Permeability Anisotropy Calculation SHEET 1 OF 9 SHEETS

METHOD FROM: "Analytical Solutions for Steady State Gas Flow to a Soil Vapor Extraction Well", Shan, C, R.W. Falta, and I. Janvandel, Water Resources Research, Vol 28, No 4, pgs 1105 - 1120, April 1992.

DATA FROM: Steady State Readings Recorded at the Galena TS site on Feb 6, 1994.

DATA TABLE

Pt	Point ID	Pressure Reading (in. H_2O)	Distance from Extraction Well (FT)	Elev (msl)
1	V-1D	4.6	14.11	129.1
2	V-7S	2.6	37.04	134.8

PROCEDURE:

STEP 1. Calculate the Radial Ratio, $C_1 = \frac{r_1}{r_2}$

$$C = \frac{14.11}{37.04} = 0.381$$

STEP 2. Calculate the pressure ratio,

$$B = \left[\frac{1 - (P_1/P_a)^2}{1 - (P_2/P_a)^2} \right]$$

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CALCULATION SHEET

CALC. NO.

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PROJECT Galena TS JOB NO.

SUBJECT Anisotropy Calculation SHEET 2 OF 9 SHEETS

$$Pa = 2116\ \mathrm{lb/FT^2} * \frac{1\ \mathrm{FT^3}\text{-}\mathrm{H_2O}}{62.4\ \mathrm{lb}} = 33.91\ \mathrm{FT}\text{-}\mathrm{H_2O} * 12 = 406.92\ \mathrm{in}\text{-}\mathrm{H_2O}$$

$$B = \left(\frac{1-(406.92-4.6/406.92)^2}{1-(406.92-2.6/406.92)^2} \right) = \frac{0.0225}{0.0127} = 1.77$$

STEP 3. Calulate a_d and b_d, and L/h where

$$a_d = \frac{a}{h} \quad ; \quad b_d = \frac{b}{h} \quad ;$$

a = depth to bottom of screen (ft) = 30 ft
b = depth to Top of screen (ft) = 6 ft
h = Thickness of unsaturated stratum (ft) = 30 ft
$L = a - b$

$a_d = 1 \quad b_d = 0.2 \quad ; \quad L/H = 0.8$

STEP 4. Using TABLE below, choose the case that best approximates the field geometry.

TABLE 2. Well Screen Locations

Well Screen Location	Depth to Bottom of Screen (a_d)	Depth to Top of Screen (b_d)	Screen Length (L/h)
[✓ A]	0.9	0.1	0.8
B	0.7	0.1	0.6
C	0.9	0.3	0.6
D	0.5	0.1	0.4
E	0.7	0.3	0.4
F	0.9	0.5	0.4
G	0.3	0.1	0.2
H	0.6	0.4	0.2
I	0.9	0.7	0.2

CASE A is selected

CALCULATION SHEET

CALC. NO. ______

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SUBJECT Anisotropy Calculation SHEET 3 OF 9 SHEETS

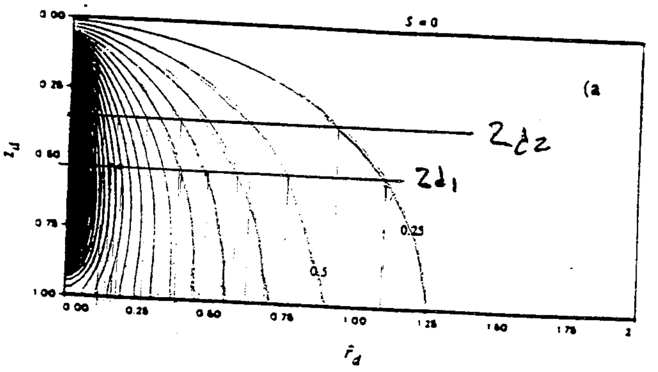
STEP 5. Calculate Dimensionless Depths, Zd_1 & Zd_2

$$Z_{d_1} = \frac{Z_1}{h} \quad ; \quad Z_{d_2} = \frac{Z_2}{h}$$

NOTE:
Avg Surface
Elevation = 145 msl

$$Zd_1 = \frac{(145 - 129.1)}{30} = 0.53 \quad ; \quad Zd_2 = \frac{(145 - 134.8)}{30} = 0.34$$

STEP 6. Using the appropriate dimensionless drawdown plot for case selected in 4, draw a horizontal line at $Z\hat{d} = Zd_1$ and record the value of $\hat{S}$ versus $\hat{r}_d$ of the intersection points.



R①	S①
$\hat{r}_d$	S
.1	3
.2	2.25
.3	1.75
.35	1.25
.475	1.0
.75	0.5
1.1	0.25

These values will be referred to as $R^{(1)}$ and $S^{(1)}$

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SUBJECT Anisotropy Calculation SHEET 4 OF 9 SHEETS

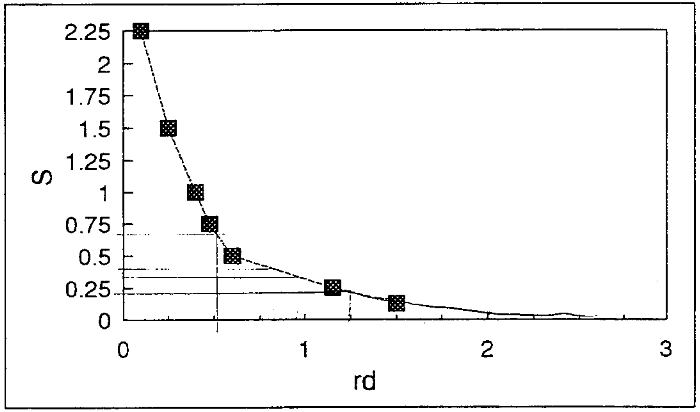
STEP 7. Compute the corresponding values of $R^{②}$ from

$$R^{②} = \frac{R^{①}}{C}$$

$R^{①}$	$R^{②}$
.1	0.26
.2	0.52
.3	0.79
.35	0.92
.475	1.25
.75	1.97
1	2.9

STEP 8. Using the same dimensionless plot as in Step 6, repeat step 6 for $z_d = z_{d2}$, and prepare a plot of S verses $\hat{r}_d$.

$\hat{r}_d$	S
1.15	.25
0.6	.50
0.475	.75
0.4	1.0
.25	1.5
.1	2.25



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SUBJECT Anisotropy Calculation SHEET 5 OF 9 SHEETS

STEP 9. From Graph in 8, find values of S corresponding to values of $R^{②}$. Those will be $S^{②}$.

$R^{②}$	$S^{②}$
.26	1.5
.52	0.7
.8	0.4
.92	0.35
1.25	0.22
2.	0.05
2?	~0

STEP 10. Using the $S^{①}$ and $S^{②}$ values corresponding to each $R^{①}$, produce a plot of $S^{①}/S^{②}$ vs. $R^{①}$.

$\boxed{B = 1.8}$

$R^{①}$	$S^{①}$	$S^{②}$	$S^{①}/S^{②}$
.1	3	1.5	2 ←
.2	2.25	0.70	3.214
.3	1.75	0.40	4.375
.35	1.25	0.35	3.571
.475	1	0.22	4.55
.75	0.5	.05	10

STEP 11.

Find $R^{①}$ value for which $S^{①}/S^{②} = B$
denote this as $R^{①*}$

$R^{①*} = 0.1$

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STEP 12. Calculate the permeable anisotropy ratio from

$$A = \frac{k_z}{k_r} = \left(\frac{R^{(1)*} h}{r_1}\right)^2$$

$$A = \left(\frac{0.1\,(30)}{14.11}\right)^2 = 0.0452$$

STEP 13. Compute the radial gas permeability of the medium from.

$$k_r = \frac{\mu \, \mathring{m}}{2\pi P_a \rho_a}\left(\frac{S^{(1)*}}{1-(P_1/P_a^2)}\right)$$

where, $S^{(1)*}$ is the value of S @ $r_d = R^{(1)*}$

$\mu = 1.76 \times 10^{-5}$ Kg/m - s

$P_a = 101{,}325$ ~~Pa~~ Kg/s² -m

$\rho_a = 1.24$ Kg/m³

$S^{(1)*} = 3$

$\mathring{M} = 137 \text{ ft}^3/\text{min} * \frac{1 \text{ m}^3}{(3.28)^3 \text{ ft}^3} = 3.88 \text{ m}^3/\text{min}$

$\mathring{m} = \mathring{M} \cdot \rho_a =$

$3.88 \text{ m}^3/\text{min} * 1.24 \text{ Kg/m}^3 = 4.81 \text{ Kg/min}$

$= 0.0802 \text{ Kg/s}$

$$k_r = \frac{1.76 \times 10^{-5}\ \text{Kg/m-s}\,(0.0802\ \text{Kg/s})}{2\pi\left(101{,}325\ \frac{\text{Kg}}{\text{s}^2\text{-m}}\right)\left(1.24\ \text{Kg/m}^3\right)}\left[\frac{3}{1-\left(\frac{406.92-4.1}{406.92}\right)^2}\right]$$

$$k_r = 1.788 \times 10^{-12}\left[133.45\right] = 2.39 \times 10^{-10}\ \text{m}^2 * \frac{(100\,\text{cm})^2}{\text{m}^2}$$

$$= \boxed{2.39 \times 10^{-6}\ \text{cm}^2}$$

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SUBJECT ANISotropy Calculation SHEET 7 OF 9 SHEETS

Step 14. Compute the vertical gas permeability as

$$k_z = k_r A$$

$$k_z = 2.39 \times 10^{-6} \text{cm}^2 * 0.0452$$

$$\boxed{= 1.08 \times 10^{-7} \text{cm}^2}$$

STEP 15. Check the result by calculating the gAS pressure at the second observation point

$$P_2 = P_a \left(1 - \frac{\mu \dot{m} S^{\textcircled{2}*}}{2\pi k_r P_a} \right)^{1/2}$$

$S^{\textcircled{2}*}$ = 1.5 S @

$\hat{r}_d = \frac{R^{\textcircled{1}*}}{C}$

$S^{\textcircled{2}*} = 1.5$

$$P_2 = 406.92 \text{ in. } H_2O \left(1 - \frac{\overset{\mu}{\left(1.76 \times 10^{-5} \frac{kg}{m \cdot s}\right)} \overset{\dot{m}}{\left(0.0802 \ kg/s\right)} \overset{S}{\left(1.5\right)}}{2\pi \underset{k}{\left(2.39 \times 10^{-10} m^2\right)} \underset{P}{\left(101325 \frac{kg}{s^2 \cdot m}\right)} \underset{c}{\left(1.29 \frac{kg}{m^3}\right)}} \right)^{1/2}$$

$$= 406.92 \text{ in. } H_2O \ (0.9944)$$

$= 404.63$ absolute or $\boxed{2.3 \text{ in } H_2O \text{ gauge} \quad \text{Actual} = 2.6}$ 12% error

checks ok

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PROJECT Gelert TS JOB NO.

SUBJECT Shaw et al Model SHEET ~~7~~ 8 OF 9 SHEETS

$kz := 1.08\cdot 10^{-7}\cdot cm^2$ $kr := 2.39\cdot 10^{-6}\cdot cm^2$ $h := 9.1\cdot m$ $a := 9.1\cdot m$ $b := 1.8\cdot m$

$\mu := 1.76\cdot 10^{-5}\cdot\frac{kg}{m\cdot sec}$ $M := 0.0802\cdot\frac{kg}{sec}$ $Pa := 1\cdot atm$ $\rho := 1.24\cdot\frac{kg}{m^3}$

$i := 1..20$ $j := 1..10$ $k := 1..500$

$ad := \frac{a}{h}$ $bd := \frac{b}{h}$ $\varepsilon := \frac{\mu\cdot M}{2\cdot\pi\cdot kr\cdot Pa\cdot\rho\cdot(a-b)}$

$n := 1..20$

$$S(rd,zd) := \ln\left[\frac{(ad-zd)+\left[rd^2+(ad-zd)^2\right]^{\frac{1}{2}}}{(bd-zd)+\left[rd^2+(bd-zd)^2\right]^{\frac{1}{2}}}\cdot\frac{(bd+zd)+\left[rd^2+(bd+zd)^2\right]^{\frac{1}{2}}}{(ad+zd)+\left[rd^2+(ad+zd)^2\right]^{\frac{1}{2}}}\right]-\sum_{n}(-1)^n\cdot\ln\left[\frac{ad+zd+2\cdot n+\left[rd^2+(ad+zd+2\cdot n)^2\right]^{\frac{1}{2}}}{bd+zd+2\cdot n+\left[rd^2+(bd+zd+2\cdot n)^2\right]^{\frac{1}{2}}}\cdot\frac{ad+zd-2\cdot r}{bd+zd-2\cdot r}\right.$$

$$\left.\frac{+\left[rd^2+(ad+zd-2\cdot n)^2\right]^{\frac{1}{2}}}{+\left[rd^2+(bd+zd-2\cdot n)^2\right]^{\frac{1}{2}}}\cdot\frac{-ad+zd+2\cdot n+\left[rd^2+(-ad+zd+2\cdot n)^2\right]^{\frac{1}{2}}}{-bd+zd+2\cdot n+\left[rd^2+(-bd+zd+2\cdot n)^2\right]^{\frac{1}{2}}}\cdot\frac{-ad+zd-2\cdot n+\left[rd^2+(-ad+zd-2\cdot n)^2\right]^{\frac{1}{2}}}{-bd+zd-2\cdot n+\left[rd^2+(-bd+zd-2\cdot n)^2\right]^{\frac{1}{2}}}\right]$$

$$\psi(rd,zd) := -\varepsilon\cdot rd\cdot\left[\frac{rd-ad-zd+\left[(ad+zd)^2+rd^2\right]^{\frac{1}{2}}}{rd+ad+zd+\left[(ad+zd)^2+rd^2\right]^{\frac{1}{2}}}+\frac{rd-ad+zd+\left[(ad-zd)^2+rd^2\right]^{\frac{1}{2}}}{rd+ad-zd+\left[(ad-zd)^2+rd^2\right]^{\frac{1}{2}}}-\frac{rd-bd-zd+\left[(bd+zd)^2+rd^2\right]^{\frac{1}{2}}}{rd+bd+zd+\left[(bd+zd)^2+rd^2\right]^{\frac{1}{2}}}-\frac{rd-bd+zd+\left[(bd-zd)\right.}{rd+bd-zd+\left[(bd-zd)\right.}\right.$$

$$\left.\frac{+rd^2\right]^{\frac{1}{2}}}{+rd^2\right]^{\frac{1}{2}}}-\sum_{n}(-1)^n\cdot\left[\frac{rd-bd-zd-2\cdot n+\left[(bd+zd+2\cdot n)^2+rd^2\right]^{\frac{1}{2}}}{rd+bd+zd+2\cdot n+\left[(bd+zd+2\cdot n)^2+rd^2\right]^{\frac{1}{2}}}+\frac{rd-bd-zd+2\cdot n+\left[(bd+zd-2\cdot n)^2+rd^2\right]^{\frac{1}{2}}}{rd+bd+zd-2\cdot n+\left[(bd+zd-2\cdot n)^2+rd^2\right]^{\frac{1}{2}}}+\frac{rd+bd-zd-2\cdot n+\left[(-bd+zd+2\cdot n)^2+rd^2\right]^{\frac{1}{2}}}{rd+-bd+zd+2\cdot n+\left[(-bd+zd+2\cdot n)^2+rd^2\right]^{\frac{1}{2}}}+\frac{rd-}{rd+}\right.$$

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$$\frac{-bd-zd+2\cdot n+\left[\left(-bd+zd-2\cdot n\right)^{2}+rd^{2}\right]^{\frac{1}{2}}}{-bd+zd-2\cdot n+\left[\left(-bd+zd-2\cdot n\right)^{2}+rd^{2}\right]^{\frac{1}{2}}}-\frac{rd-ad-zd-2\cdot n+\left[\left(ad+zd+2\cdot n\right)^{2}+rd^{2}\right]^{\frac{1}{2}}}{rd+ad+zd+2\cdot n+\left[\left(ad+zd+2\cdot n\right)^{2}+rd^{2}\right]^{\frac{1}{2}}}-\frac{rd-ad-zd+2\cdot n+\left[\left(ad+zd-2\cdot n\right)^{2}+rd^{2}\right]^{\frac{1}{2}}}{rd+ad+zd-2\cdot n+\left[\left(ad+zd-2\cdot n\right)^{2}+rd^{2}\right]^{\frac{1}{2}}}-\frac{rd+ad-zd-2\cdot n+\left[\left(-ad+z\right.\right.}{rd+-ad+zd+2\cdot n+\left[\left(-ad+z\right.\right.}$$

$$\frac{+2\cdot n)^{2}+rd^{2}\Big]^{\frac{1}{2}}}{d+2\cdot n)^{2}+rd^{2}\Big]^{\frac{1}{2}}}-\frac{rd+ad-zd+2\cdot n+\left[\left(-ad+zd-2\cdot n\right)^{2}+rd^{2}\right]^{\frac{1}{2}}}{rd+-ad+zd-2\cdot n+\left[\left(-ad+zd-2\cdot n\right)^{2}+rd^{2}\right]^{\frac{1}{2}}}\Bigg]\Bigg]$$

$$\psi d(rd,zd):=\frac{\psi(rd,zd)}{\psi(rd,1)}\qquad P(r,z):=Pa\cdot\sqrt{1-\varepsilon\cdot S\left(\sqrt{\frac{kz}{kr}}\cdot\frac{r}{h},\frac{z}{h}\right)}$$

$$B_{k,1}:=ceil\left(\frac{k}{10}\right)\qquad B_{k,2}:=mod(k,10)\qquad B_{k,3}:=\frac{P\left(B_{k,1}\cdot m,B_{k,2}\cdot m\right)}{Pa}$$

interrupted

$$B_{k,4}:=\psi d\left(\sqrt{\frac{kz}{kr}}\cdot\frac{B_{k,1}\cdot m}{h},\frac{B_{k,2}\cdot m}{h}\right)$$

interrupted

WRITEPRN(SVEDTAe2) := B

APPENDIX C.5

Helium Tracer Test

APPENDIX C.6

In Situ Respiration Procedures and Calculations

In Situ Respiration Test Procedure

The soil respiration tests were conducted in accordance with the procedures outlined in the work plan. O_2 and CO_2 concentrations in the soil gas were measured immediately following shutdown of the SVE and AS blowers in four to eight vapor probe locations in each test cell. O_2 and CO_2 concentrations were measured several times during the first day of the test, and approximately every 12 hours for the remainder of the test. Hydrocarbon concentrations at each location were measured at the beginning and end of the test period during the 150 day test.

Measurement locations were selected to cover both shallow and deep probe locations across the entire study area. Because the temperature rise in subsurface soils in the West Cell may be associated with biological activity, assessing the variation in hydrocarbon degradation rates with temperature was one of the major objectives of the soil respiration tests.

Because of time constraints imposed by other sampling requirements, the SVE system was only allowed to operate overnight before it was shut down to begin the day 60 respiration test. In light of the high air permeability observed in an earlier test, it was believed that 12 hrs of operation would be enough for the soil gases to approach equilibrium. The low and erratic initial oxygen measurements at some vapor probes suggest that equilibrium may not have been fully achieved before the day 60 respiration test was started.

At each vapor probe location, the soil gas O_2 and CO_2 concentrations were measured with a TraceTechtor™ meter. The meter was calibrated daily with a nitrogen blank gas, ambient air (20.9% O_2 and 0.03% CO_2), and a 5% CO_2 standard gas; in addition, the calibration was checked frequently against ambient air to correct for drift as the instrument cooled to ambient temperatures. Soil gas hydrocarbon concentrations were measured with a similar approach, using a TraceTector™ hydrocarbon analyzer for quantification. A 40% LEL hexane standard was used to calibrate the instrument. Soil temperatures were determined using bare-lead thermocouples installed in the soil concurrent with vapor probe installation (deep thermocouples) or by pushing a bare-lead thermocouple down the vapor probe tubing (shallow thermocouples). Temperatures were read using a Cole-Parmer Digi-sense digital thermometer calibrated with ice-water at 0°C and a warm water bath at approximately 35°C against a mercury-in-glass thermometer.

The vapor probes were purged using a peristaltic pump for 2 to 3 minutes at a rate of 0.3 to 1.0 L/min. During the day 60 test a filter housing on the O_2/CO_2 meter cracked, allowing ambient air to mix with the soil gas being sampled. These air leaks required that a higher gas flow rate be used to provide a stable, accurate reading. This contamination was worse on the 24-hr interval samples, after which the leak was noticed and corrected. The contamination was more apparent at locations where the gas flow rate drawn from the vapor probe was not significantly larger than the flow required by the meter. Values for the 12- and 24-hr sampling intervals which appeared to be significantly affected by this air leakage were excluded from subsequent calculations.

Oxygen utilization rates were calculated from the field data using a linear regression formula. Outlier data affected by air contamination were excluded from these calculations as described above.

Respiration rates were calculated using the following formula:

$$K = (K_{O2}/100) * (R/R_t) * (\theta/\rho_b) * (MW) * (1000/11)$$

where

K = biodegradation rate (mg/kg/day)
K_{O2} = oxygen utilization rate (%/day)
P = pressure (atm)
R = gas constant (82.05×10^{-6} atm m^3/gmol K)
T = temperature (K)
θ = effective air porosity
ρ_b = bulk density (kg/m^3)

MW = molecular weight for heptane (100 g/gmol)

In calculating the hydrocarbon degradation rates only the oxygen utilization data was used. The CO_2 production rates are generally lower and more variable than the oxygen utilization rates, reflecting carbon uptake by microorganism growth and production of intermediate hydrocarbon compounds not measured in this experiment. Heptane (C_7H_{16}) was used to represent the average hydrocarbon composition in the POL Tank Farm soils. Both lighter and heavier hydrocarbons are known to be present.

The hydrocarbon degradation rates calculated using this formula ignore the effects of the oxidation of other soil materials and assume the complete utilization of oxygen consumed for hydrocarbon degradation. Oxygen may also be consumed through oxidation of naturally occurring buried organic matter or oxidation of mineral materials such as reduced forms of iron or manganese. The background oxygen consumption through these mechanisms was not specifically measured at this site; however, the near zero soil respiration rates measured in the east unit suggest that the background respiration rate is much smaller than the hydrocarbon respiration observed rate at this site.

Incomplete oxidation of hydrocarbons is also possible. Incomplete oxidation may result in removal of larger amounts of contamination than calculated above. Incomplete oxidation products may be incorporated into microorganisms, dissolved and entrained in groundwater, or lost to the atmosphere.

Table C-9
Soil Respiration Test Results

Test Day	Location	Initial O_2 (%)	O_2 Utilization (%/day)	CO_2 Production (%/day)	Temperature (C)	Hydrocarbon Concentration (ppmV)	K (mg/kg soil/day)
60	V-1S	19.8	8.20	1.34	7.4	3500	7.81
60	V-1D	20.5	2.52	0.82	0.5	1500	2.46
60	V-2S	15.0	3.70	1.48	14.1	8400	3.44
60	V-3D	10.0	2.45	0.29	1.4	>10000	2.38
60	V-4D	5.9	2.20	0.96	10.7	9200	2.07
60	V-6D	19.0	0.65	0.00	0.1	4800	0.64
60	V-8S	20.9	1.99	0.49	1.6	140	1.94
60	V-8D	19.2	1.99	0.98	NA	9000	1.95
150	V-1S	20.0	4.62	1.55	24.6	170	4.15
150	V-1D	20.9	2.39	1.22	18.6	120	2.19
150	V-2S	12.0	2.55	1.06	33.6	1100	2.22
150	V-3D	14.5	4.97	2.50	18.9	3900	4.55
150	V-4D	8.5	2.27	0.57	NA	4200	2.22
150	V-8D	17.0	-1.38	-0.81	NA	1600	-1.35
150	V-14S	20.0	0.34	0.07	0.4	140	0.33
150	V-14D	19.5	-0.09	0.10	NA	320	-0.09
150	V-15S	20.4	0.12	0.08	1.3	18	0.12
150	V-15D	20.2	0.26	0.14	NA	20	0.25

RADIAN CORPORATION

CALCULATION SHEET

CALC. NO.
SIGNATURE Whitney Delaney DATE 5/10/94 CHECKED J. Rehage DATE 5/11/94
PROJECT Galena Airport TS JOB NO.
SUBJECT Biodegradation Rate from In Situ Respiration Tests from Phase II Test SHEET 1 OF 1 SHEETS

Reference for Calculation : Hinchee, R.E. and S.K. Ong

~~Assume~~ Oxidation of Heptane

$$C_7H_{16} + 11O_2 \rightarrow 7CO_2 + 8H_2O$$

$$K = \frac{K_{O_2}}{100} \cdot \frac{P}{RT} \cdot \frac{\theta}{\rho_b} \cdot \text{mw heptane} \cdot \frac{1000}{11}$$

K = biodegradation rate, mg/kg/day
K_{O_2} = O_2 uptake rate, $\%O_2$/day
P = pressure, atm
R = 82.05×10^{-6}, atm m^3/gmol K
T = temperature, K
θ = effective air porosity = 0.446 cm^3/cm^3
ρ_b = bulk density of soil, (kg/m^3) = 1770 kg/m^3
mw = 100, g/gmol

Assume : $\dfrac{\theta}{\rho_b} = 2.52 \times 10^{-4}\ m^3/kg$

Example : Day 60 Test at V-1S

~~θ~~ K_{O_2} = 8.2 %/day & T = 7.4 °C = ~~280.4K~~ 280.4 K
(field measurement, linear regression)

$$K = \frac{8.2\ \%/day}{100\ \%} \cdot \frac{1\ atm}{\underset{\frac{atm\ m^3}{gmol\ K}}{(82.05 \times 10^{-6})}\underset{K}{(280.4)}} \cdot 2.52 \times 10^{-4}\ \frac{m^3}{kg} \cdot 100\ \frac{g}{gmol} \cdot \frac{1000\ \frac{g}{kg}}{11}$$

= 8.2 mg/kg/day as heptane

10-88-30702

References

Hinchee, R.E., and S.K. Ong. "A Rapid In Situ Respiration Test for Measuring Aerobic Biodegradation Rates of Hydrocarbons in Soil." *Journal of the Air and Waste Management Association.* 42(10):1305-1312, October 1992.

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Shan, C., R.W. Falta, and I. Javandel. "Analytical Solutions for Steady State Gas Flow to a Soil Vapor Extraction Well." *Water Resources Research.* 28(4):1105-1120, April 1992.

APPENDIX D

Recovery Tests for Light Nonaqueous Phase Liquids (LNAPL)

APPENDIX D.1

Phase I Testing, September 1992

Table D-1

Baildown Measurements for Recovery Well 05-RW-01

Date	Time	Elapsed Time (min)	Product Level (feet)	Water Level (feet)	Product Thickness (feet)
09/17/92	13:00	0	17.75	19.3	1.55
09/17/92	14:15	76	18.1	18.25	0.15
09/17/92	14:19	80	18.1	18.25	
09/17/92	14:24	85	18.1	18.25	
09/17/92	14:30	90	18.1	18.25	
09/17/92	14:44	105	18.08	18.27	0.19
09/17/92	15:00	120	18.08	18.27	
09/17/92	15:15	135	18.07	18.28	0.21
09/17/92	15:29	150	18.07	18.28	
09/17/92	15:45	165	18.07	18.28	
09/17/92	16:00	180	18.06	18.28	0.22
09/17/92	16:14	195	18.06	18.28	
09/17/92	16:30	210	18.06	18.28	
09/17/92	16:59	240	18.06	18.29	0.23
09/17/92	17:30	270	18.05	18.28	
09/17/92	18:30	330	18.07	18.31	0.24
09/17/92	19:30	390	18.07	18.32	
09/18/92	07:30	1110	18.12	18.44	0.32
09/18/92	08:30	1170	18.12	18.44	
09/18/92	10:30	1290	18.12	18.47	0.35
09/18/92	14:30	1530	18.16	18.52	0.36
09/18/92	16:30	1650	18.17	18.53	
09/19/92	08:30	2610	18.26	18.66	0.4
09/19/92	10:30	2730	18.26	18.66	
09/19/92	12:29	2850	18.29	18.66	
09/19/92	16:30	3090	18.29	18.66	
09/20/92	13:30	4350	18.39	18.78	
09/20/92	17:55	4615	18.47	18.87	

Figure D-1. Baildown Test Results for Recovery Well 05-RW-01

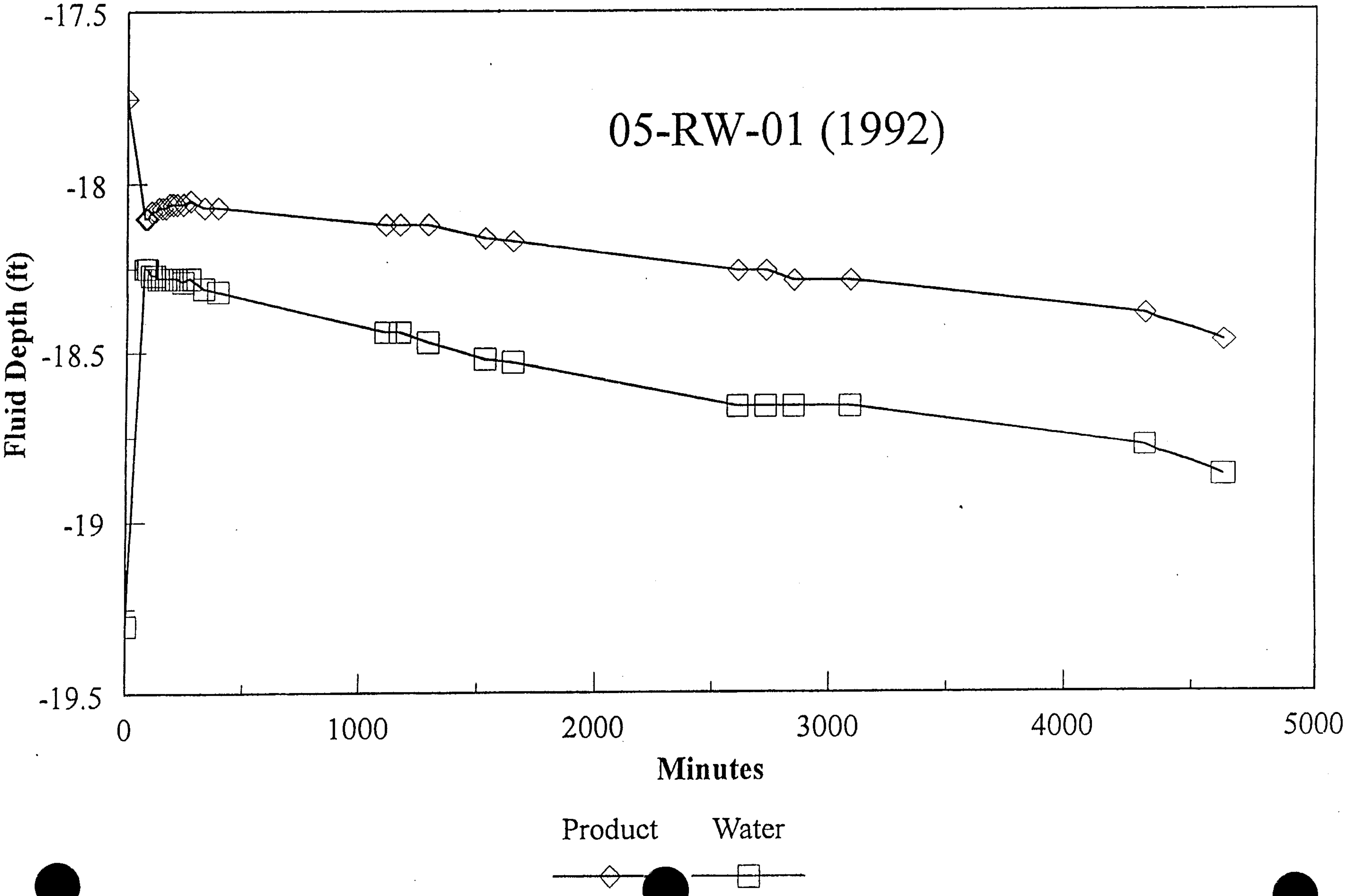
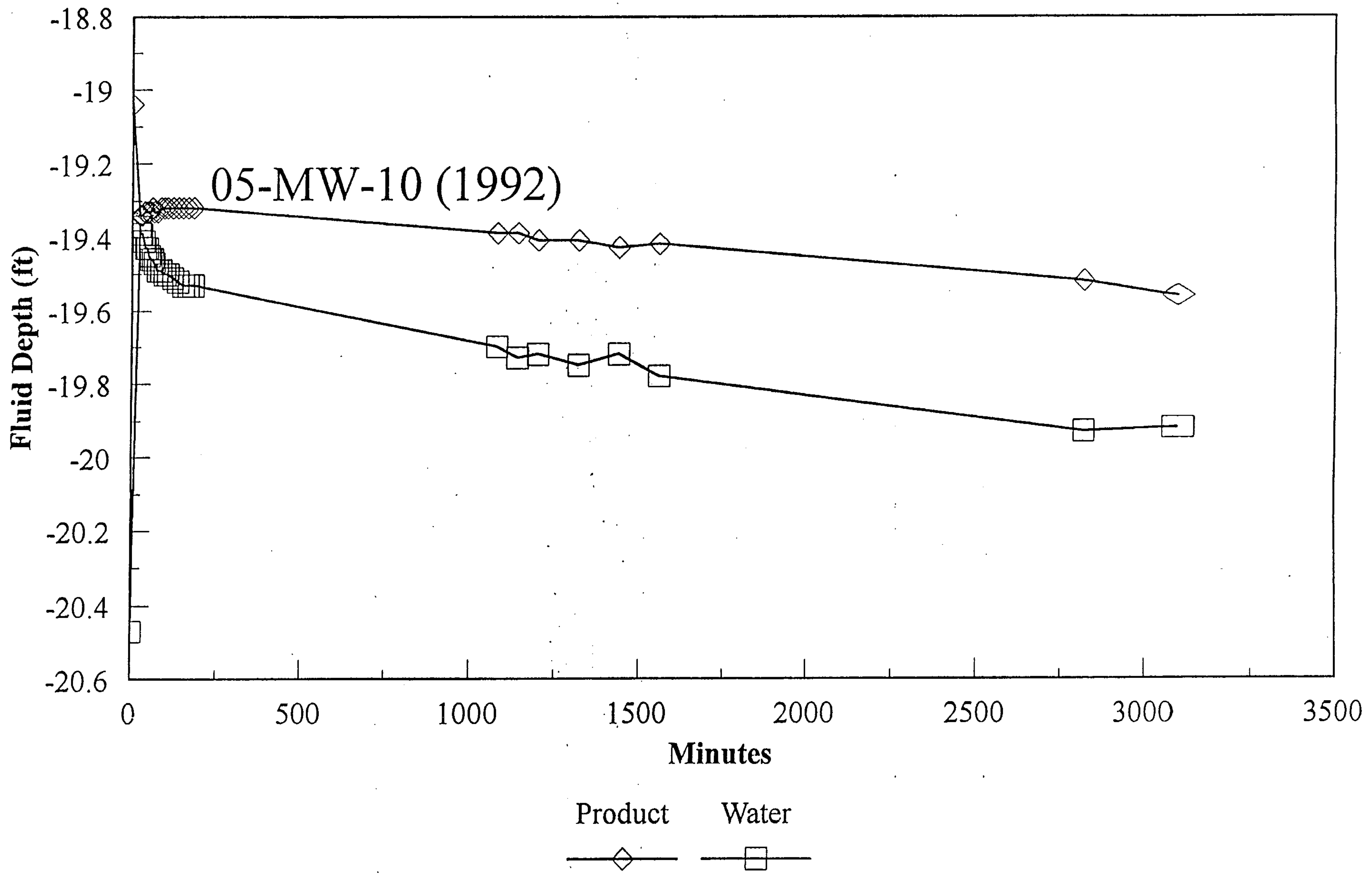


Table D-2. Baildown Measurements for Monitor Well 05-MW-10

Date	Time	Elapsed Time (min)	Product Level (feet)	Water Level (feet)	Product Thickness (feet)
09/18/92	14:30	0	19.04	20.47	1.43
09/18/92	14:53	23	19.34	19.37	0.03
09/18/92	14:55	25	19.34	19.39	
09/18/92	14:57	28	19.34	19.39	
09/18/92	15:00	30	19.34	19.39	
09/18/92	15:04	35	19.33	19.41	
09/18/92	15:09	40	19.33	19.43	0.1
09/18/92	15:15	45	19.33	19.43	
09/18/92	15:20	50	19.33	19.45	
09/18/92	15:24	55	19.33	19.46	
09/18/92	15:29	60	19.32	19.46	
09/18/92	15:35	65	19.33	19.47	
09/18/92	15:45	75	19.33	19.49	
09/18/92	15:54	85	19.32	19.49	
09/18/92	16:05	95	19.32	19.5	
09/18/92	16:14	105	19.32	19.5	
09/18/92	16:30	120	19.32	19.51	
09/18/92	16:45	135	19.32	19.52	0.2
09/18/92	16:59	150	19.32	19.53	
09/18/92	17:15	165	19.32	19.53	
09/18/92	17:30	180	19.32	19.53	
09/19/92	08:30	1080	19.39	19.7	0.31
09/19/92	09:29	1140	19.39	19.73	
09/19/92	10:30	1200	19.41	19.72	
09/19/92	12:29	1320	19.41	19.75	
09/19/92	14:30	1440	19.43	19.72	
09/19/92	16:30	1560	19.42	19.78	
09/20/92	13:30	2820	19.52	19.93	0.41
09/20/92	17:55	3085	19.56	19.92	

Figure D-2. Baildown Test Results for Monitor Well 05-MW-10



APPENDIX D.2

Phase II Testing
July 1993

Table D-3. Skimming Test Measurements for Recovery Well 05-RW-01

Site 5 Recovery Well 1

Date	Time	Baseline	Product Height	Water Height	Product Thickness	Pump		Comments
						On	Off	
13-Jul-93	1620	5	-13.61	-14.5	0.89			
14-Jul-93	900	1005	-13.73	-15.73	2.00			
	Began Skimming							
	1346	1291	-13.69	-15.75	2.06	2	0	
	1419	1324	-13.74	-15.63	1.89			
	1432	1337	-13.79	-15.52	1.73			
	1515	1380	-13.86	-15.19	1.33	1	20	Replaced Batteries in Probe
	1530	1395	-13.89	-15.05	1.16			
	1603	1428	-13.91	-14.91	1.00			
	1625	1450	-13.95	-14.85	0.90			
	1647	1472	-13.97	-14.71	0.74			
	1701	1486	-13.98	-14.73	0.75			
	1714	1499	-14	-14.67	0.67			
	1728	1513	-14.02	-14.61	0.59			
15-Jul-93	815	2400	-14.03	-14.8	0.77			
	Began Skimming							
	820	2405	-14.03	-14.8	0.77	1	40	
	851	2436	-14.04	-14.76	0.72	1	50	
	916	2461	-14.06	-14.7	0.64			
	934	2479	-14.09	-14.6	0.51			
	1005	2510	-14.09	-14.58	0.49			
	1042	2547	-14.11	-14.56	0.45			
	1150	2615	-14.11	-14.55	0.44			Skimmer Lowered at 1104
	1300	2685	-14.11	-14.59	0.48			Compressor Motor Overheating
	1326	2711	-14.12	-14.49	0.37			
	1343	2728	-14.12	-14.48	0.36			
	1425	2770	-14.14	-14.34	0.20			
	1520	2825	-14.13	-14.48	0.35			Compressor Motor Overheating
	1530	2835	-14.11	-14.48	0.37			
	1540	2845	-14.11	-14.48	0.37			
	1600	2865	-14.12	-14.43	0.31			
	1622	2887	-14.14	-14.38	0.24			
	1631	2896	-14.13	-14.36	0.23			
	1642	2907	-14.15	-14.35	0.20			
	1703	2928	-14.16	-14.3	0.14			
	1716	2941	-14.17	-14.25	0.08			
	1746	2971	-14.17	-14.23	0.06			
	1758	2983	-14.18	-14.23	0.05			

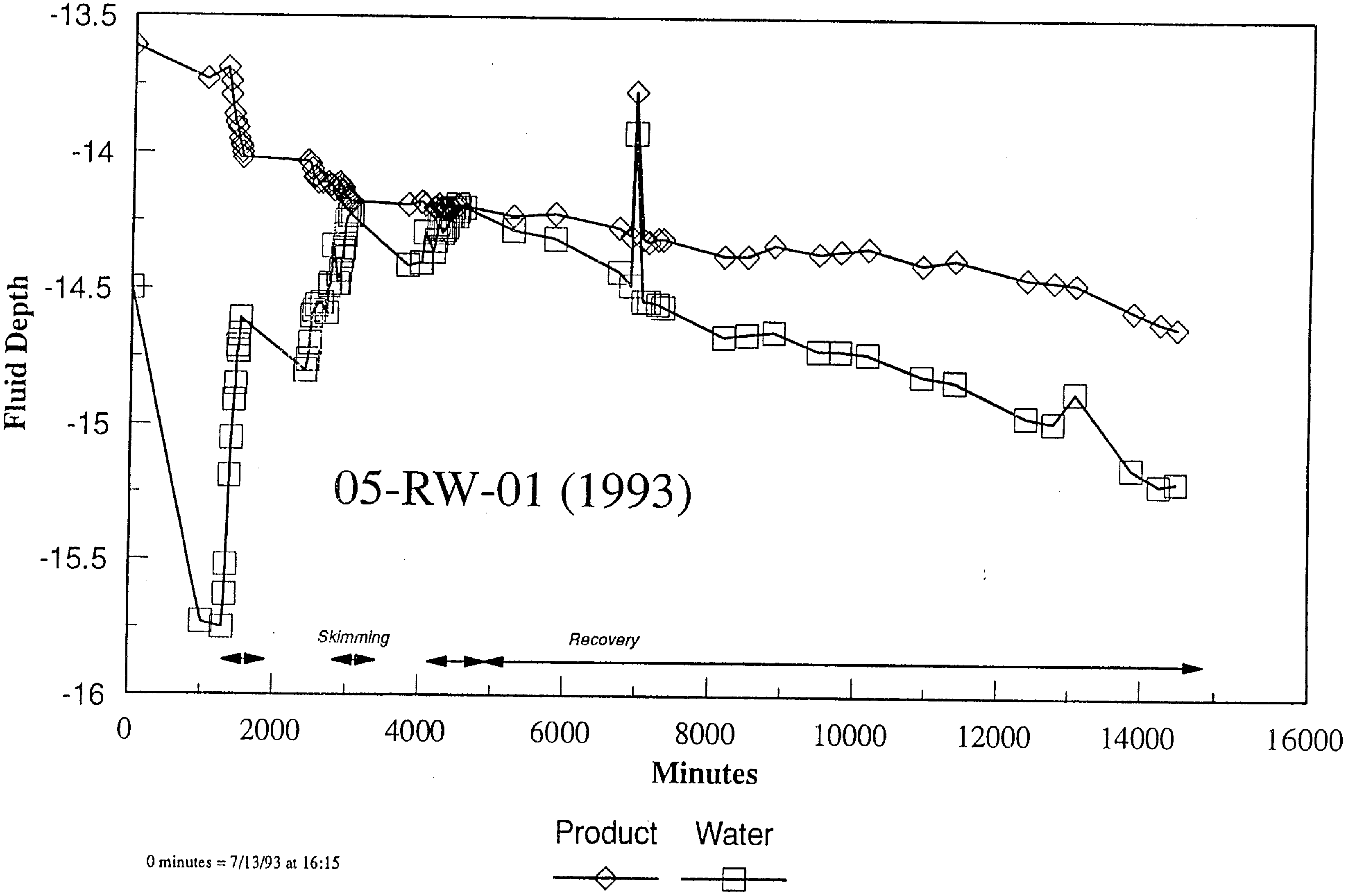
Table D-3. (Continued)

	1835	3020	-14.18	-14.23	0.05		
16-Jul-93	730	3795	-14.19	-14.41	0.22		
	1025	3970	-14.18	-14.4	0.22		
	Began Skimming						
	1038	3983	-14.18	-14.4	0.22	1.5	180
	1120	4025	-14.19	-14.29	0.10		
	1322	4147	-14.2	-14.36	0.16		
	1352	4177	-14.2	-14.32	0.12		
	1423	4208	-14.19	-14.26	0.07	1.5	135
	1452	4237	-14.2	-14.27	0.07		
	1521	4266	-14.2	-14.29	0.09		
	1551	4296	-14.2	-14.28	0.08		
	1622	4327	-14.2	-14.27	0.07		
	1705	4370	-14.2	-14.23	0.03		
	1731	4396	-14.2	-14.23	0.03		
	1800	4425		-14.2	0.00	5	30
	1835	4460	-14.2	-14.23	0.03		
	1845	4470	-14.19	-14.19	0.00		
	Begin Baildown Test						
	1853	4478	-14.21	-14.21	0.00		
	1854	4479	-14.2	-14.2	0.00		
	1855	4480	-14.2	-14.2	0.00		
	1857	4482	-14.21	-14.21	0.00		
	1858	4483	-14.21	-14.21	0.00		
	1859	4484	-14.2	-14.2	0.00		
	1900	4485	-14.2	-14.2	0.00		
	1901	4486	-14.2	-14.2	0.00		
	1902	4487	-14.2	-14.2	0.00		
	1903	4488	-14.2	-14.2	0.00		
	2023	4568	-14.2	-14.2	0.00		
					0.00		
17-Jul-93	743	5248	-14.23	-14.28	0.05		
	1729	5834	-14.22	-14.31	0.09		
18-Jul-93	820	6725	-14.27	-14.43	0.16		
	1103	6888	-14.3	-14.48	0.18		
	1155	6940	-13.77	-13.92	0.15		
	1353	7058	-14.31	-14.54	0.23		
	1510	7135	-14.32	-14.54	0.22		
	1713	7258	-14.31	-14.55	0.24		
	1825	7330	-14.31	-14.56	0.25		
19-Jul-93	825	8170	-14.37	-14.67	0.30		

Table D-3 (Continued)

	1345	8490	-14.37	-14.6[illegible]	0.29		
	1955	8860	-14.33	-14.65	0.32		
20-Jul-93	618	9483	-14.36	-14.72	0.36		
	1118	9783	-14.35	-14.72	0.37		
	1738	10163	-14.34	-14.73	0.39		
21-Jul-93	622	10927	-14.4	-14.81	0.41		
	1400	11385	-14.38	-14.83	0.45		
22-Jul-93	637	12382	-14.45	-14.96	0.51		
	1257	12762	-14.46	-14.98	0.52		
	1800	13065	-14.47	-14.87	0.40		
23-Jul-93	721	13866	-14.57	-15.15	0.58		
	1340	14245	-14.61	-15.21	0.60		
	1737	14482	-14.63	-15.2	0.57		

Figure D-3. Skimming Test Results for Recovery Well 05-MW-01



0 minutes = 7/13/93 at 16:15

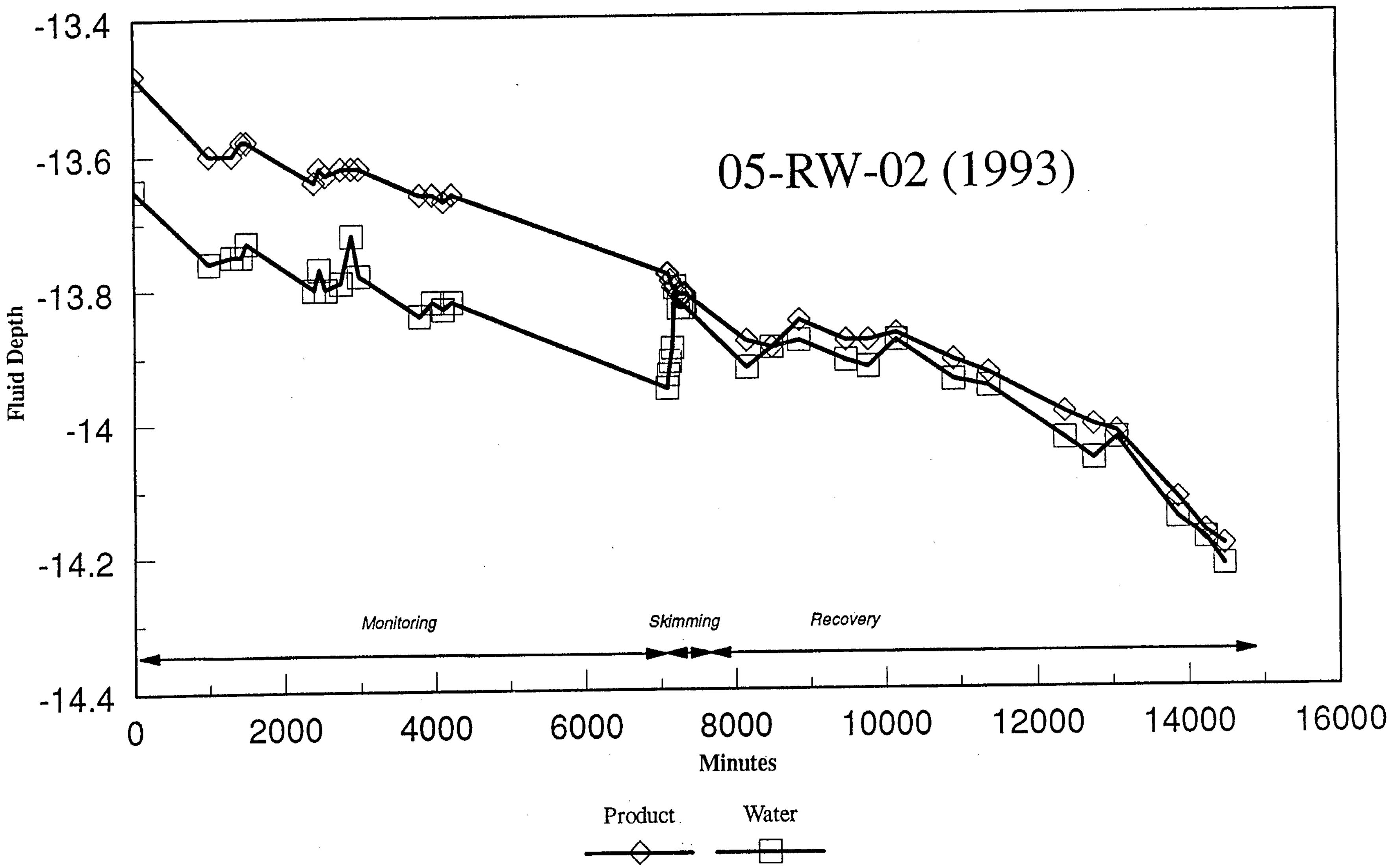
Table D-4. Skimming Test Measurem[illegible]s for Recovery Well 05-RW-02

Site 5 Recovery Well 2								
Date	Time	(Baseline)	Prod. Ht.	Water Ht.	Prod. Th.	Pump		Comments
13-Jul-93	1615	0	-13.48	-13.65	0.17			
14-Jul-93	900	1005	-13.6	-13.76	0.16			
	1407	1312	-13.6	-13.75	0.15			
	1615	1440	-13.58	-13.75	0.17			
	1720	1505	-13.58	-13.73	0.15			
15-Jul-93	815	2400	-13.64	-13.8	0.16			
	922	2467	-13.62	-13.77	0.15			
	1045	2550	-13.63	-13.8	0.17			
	1405	2750	-13.62	-13.79	0.17			
	1625	2890	-13.62	-13.72	0.10			
	1800	2985	-13.62	-13.78	0.16			
16-Jul-93	730	3795	-13.66	-13.84	0.18			
	1025	3970	-13.66	-13.82	0.16			
	1248	4113	-13.67	-13.83	0.16			
	1445	4230	-13.66	-13.82	0.16			
Begin Skimming						On	Off	
18-Jul-93	1435	7100	-13.78	-13.95	0.17	1	120	
	1450	7115	-13.78	-13.93	0.15			
	1515	7140	-13.79	-13.91	0.12			
	1545	7170	-13.8	-13.89	0.09			
	1620	7205	-13.8	-13.8	0.00	1	195	
	1705	7250	-13.81	-13.83	0.02	2	90	
	1756	7301	-13.81	-13.83	0.02			
	1820	7325	-13.81	-13.83	0.02	2	75	
	1840	7345	-13.81	-13.83	0.02	1	60	
Began Baildown								
19-Jul-93	821	8166	-13.88	-13.92	0.04			
	1350	8495	-13.89	-13.89	0.00			
	1950	8855	-13.85	-13.88	0.03			

Table D-4. (Continued)

Site 5 Recovery Well 2							
Date	Time	(Baseline)	Prod. Ht.	Water Ht.	Prod. Th.	Pump	Comments
20–Jul–93	615	9480	−13.88	−13.91	0.03		
	1115	9780	−13.88	−13.92	0.04		
	1735	10160	−13.87	−13.88	0.01		
21–Jul–93	620	10925	−13.91	−13.94	0.03		
	1357	11382	−13.93	−13.95	0.02		
22–Jul–93	635	12380	−13.99	−14.03	0.04		
	1255	12760	−14.01	−14.06	0.05		
	1755	13060	−14.02	−14.03	0.01		
23–Jul–93	718	13863	−14.12	−14.15	0.03		
	1329	14234	−14.17	−14.18	0.01		
	1734	14479	−14.19	−14.22	0.03		

Figure D-4. Skimming Test Results for Recovery Well 05-RW-02



0 minutes = 7/13/93 at 1615

Table D-5. Baildown Measurements for Monitoring Well 05-MW-04

Site 5 Monitoring Well 4							
Date	Time	(Baseline)	Prod. Ht.	Water Ht.	Prod. Th.	Pump	Comments
17-Jul-93	1530	5715	-13.42	-14	0.58		
Begin Baildown							
	1701	5806	-13.5	-13.5	0.00		
	1702	5807	-13.5	-13.5	0.00		
	1703	5808	-13.5	-13.5	0.00		
	1705	5810		-13.5			
	1708	5813	-13.5	-13.5	0.00		
	1711	5816		-13.5			
	1719	5824	-13.5	-13.51	0.01		
	1725	5830	-13.5	-13.51	0.01		
	1744	5849		-13.5			
	1901	5926	-13.49	-13.5	0.01		
18-Jul-93	1014	6839	-13.57	-13.59	0.02		
	1110	6895	-13.58	-13.58	0.00		
	1358	7063	-13.59	-13.59	0.00		
	1720	7265	-13.59	-13.60	0.01		
	1835	7340		-13.60			
19-Jul-93	835	8180	-13.66	-13.66	0.00		
	1330	8475	-13.67	-13.67	0.00		
	2010	8875		-13.63			
20-Jul-93	625	9490		-13.66			
	1123	9788		-13.67			
	1745	10170	-13.98	-13.98	0.00		
21-Jul-93	630	10935		-14.70			
	1349	11374		-13.71			
22-Jul-93	645	12390		-13.79			
	1301	12766	-13.81	-13.81	0.00		
	1803	13068		-13.81			

Table D-[illegible]Continued)

Site 5 Monitoring Well 4							
Date	Time	(Baseline)	Prod. Ht.	Water Ht.	Prod. Th.	Pump	Comments
23-Jul-93	724	13869		-13.91			
	1320	14225		-13.95			
	1730	14475		-13.99			

Figure D-5. Baildown Test Results for Monitor Well 05-MW-04

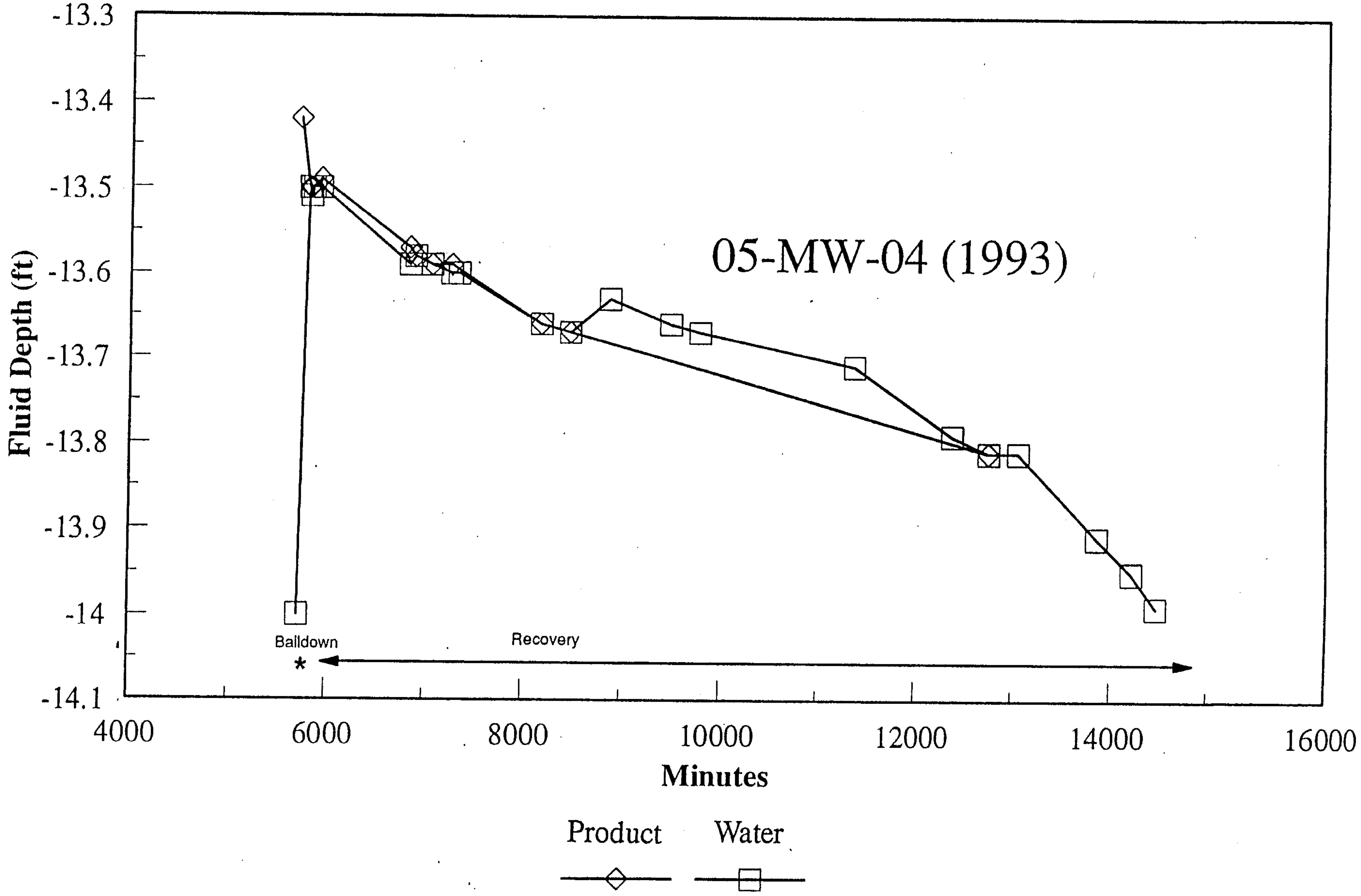


Table D-6. Baildown Measurements for Monitor Well 05-MW-10

Site 5 Monitoring Well 10

Date	Time	(Baseline)	Prod. Ht.	Water Ht.	Prod. Th.	Pump	Comments
14–Jul–93	900	1005	–15.63	–16.79	1.16		
	1403	1308	–15.65	–16.75	1.10		
	1535	1400	–15.62	–16.73	1.11		
	1611	1436	–15.61	–16.71	1.10		
	1725	1510	–15.62	–16.72	1.10		
15–Jul–93	815	2400	–15.67	–16.8	1.13		
	922	2467	–15.67	–16.78	1.11		
	1045	2550	–15.67	–16.86	1.19		
	1405	2750	–15.62	–16.75	1.13		
	1625	2890	–15.65	–16.74	1.09		
	1800	2985	–15.65	–16.72	1.07		
16–Jul–93	730	3795	–15.71	–16.81	1.10		
	1025	3970	–15.69	–16.88	1.19		
	1250	4115	–15.7	–16.78	1.08		
	1450	4235	–15.68	–16.78	1.10		
17–Jul–93	1605	5750	–15.25	–16.17	0.92		
Begin Baildown							
	1821	5886	–15.41	–15.41	0.00		
	1823	5887.5	–15.41	–15.44	0.03		
	1823	5888	–15.41	–15.47	0.06		
	1824	5889	–15.4	–15.53	0.13		
	1825	5890	–15.41	–15.56	0.15		
	1828	5892.5	–15.39	–15.64	0.25		
	1830	5894.5	–15.38	–15.71	0.33		
	1831	5896	–15.38	–15.77	0.39		
	1834	5899	–15.37	–15.83	0.46		
	1836	5901	–15.38	–15.88	0.50		
	1840	5905	–15.37	–15.9	0.53		
	1844	5908.5	–15.36	–15.91	0.55		
	1846	5911	–15.35	–15.95	0.60		
	1849	5914	–15.35	–15.94	0.59		

Table D-6. (Continued)

Site 5 Monitoring Well 10							
Date	Time	(Baseline)	Prod. Ht.	Water Ht.	Prod. Th.	Pump	Comments
	1852	5917	−15.34	−15.95	0.61		
	1855	5920	−15.34	−15.9	0.56		
18−Jul−93	830	6735	−15.32	−16.22	0.90		
Repeat Baildown							
	915	6780	−15.51	−15.51	0.00		
	916	6781	−15.51	−15.51	0.00		
	916.5	6781.5	−15.51	−15.51	0.00		
	917	6782	−15.51	−15.52	0.01		
	917.5	6782.5	−15.51	−15.51	0.00		
	918	6783	−15.51	−15.52	0.01		
	918.5	6783.5	−15.51	−15.51	0.00		
	919	6784	−15.51	−15.51	0.00		
	919.5	6784.5	−15.51	−15.52	0.01		
	920	6785	−15.51	−15.52	0.01		
	921	6786	−15.51	−15.55	0.04		
	922	6787	−15.51	−15.53	0.02		
	923	6788	−15.51	−15.53	0.02		
	924	6789	−15.51	−15.6	0.09		
	925	6790	−15.51	−15.6	0.09		
	927	6792	−15.52	−15.61	0.09		
	929	6794	−15.51	−15.67	0.16		
	931	6796	−15.52	−15.69	0.17		
	933	6798	−15.52	−15.7	0.18		
	935	6800	−15.52	−15.68	0.16		
	940	6805	−15.49	−15.69	0.20		
	945	6810	−15.49	−15.85	0.36		
	950	6815	−15.46	−15.79	0.33		
	1000	6825	−15.44	−15.94	0.50		
	1058	6883	−15.37	−16.14	0.77		
	1350	7055	−15.36	−16.15	0.79		
	1504	7129	−15.36	−16.16	0.80		
	1600	7185	−15.37	−16.18	0.81		

Table D-7. Baildown Measurements for Monitor Well 09-MW-08

Well ID: 09-MW-08							
Date	Time	(Baseline)	Prod. Ht.	Water Ht.	Prod. Th.	Pump	Comment
17-Jul-93	945	5370	−18.68	−19.68	1.00		
Begin Baildown							
	955	5380	−18.69	−19.68	0.99		
	1020	5405	−18.41	−18.43	0.02		
	1027	5412	−18.43	−18.59	0.16		
	1035.5	5420.5	−18.47	−18.49	0.02		
	1036	5421	−18.45	−18.48	0.03		
	1036.5	5421.5	−18.44	−18.62	0.18		
	1037	5422	−18.45	−18.47	0.02		
	1037.5	5422.5	−18.45	−18.46	0.01		
	1038	5423	−18.44	−18.47	0.03		
	1038.5	5423.5	−18.45	−18.47	0.02		
	1039	5424	−18.45	−18.62	0.17		
	1039.5	5424.5	−18.45	−18.64	0.19		
	1040	5425	−18.45	−18.63	0.18		
	1040.5	5425.5	−18.44	−18.64	0.20		
	1041	5426	−18.44	−18.63	0.19		
	1041.5	5426.5	−18.43	−18.64	0.21		
	1042	5427	−18.44	−18.64	0.20		
	1043	5428	−18.45	−18.46	0.01		
	1044	5429	−18.44	−18.48	0.04		
	1045	5430	−18.45	−18.63	0.18		
	1046	5431	−18.43	−18.44	0.01		
	1047	5432	−18.44	−18.45	0.01		
	1048	5433	−18.45	−18.62	0.17		
	1050	5435	−18.44	−18.62	0.18		
	1051	5436	−18.45	−18.62	0.17		
	1052	5437	−18.45	−18.63	0.18		
	1053	5438	−18.45	−18.64	0.19		
	1054	5439	−18.45	−18.63	0.18		
	1056	5441	−18.45	−18.64	0.19		
	1058	5443	−18.46	−18.63	0.17		
	1100	5445	−18.44	−18.64	0.20		
	1102	5447	−18.45	−18.64	0.19		

Table D-7. (Continued)

Well ID: 09–MW–08

Date	Time	(Baseline)	Prod. Ht.	Water Ht.	Prod. Th.	Pump	Comment
	1104	5449	−18.45	−18.63	0.18		
	1346	5611	−18.42	−18.65	0.23		
Retry Baildown							
	1353.5	5618.5	−18.47	−18.48	0.01		
	1354	5619	−18.46	−18.47	0.01		
	1354.5	5619.5	−18.46	−18.47	0.01		
	1355	5620	−18.46	−18.47	0.01		
	1356	5621	−18.45	−18.46	0.01		
	1357	5622	−18.46	−18.47	0.01		
	1358	5623	−18.45	−18.46	0.01		
	1359	5624	−18.46	−18.47	0.01		
	1400	5625	−18.45	−18.46	0.01		
	1405	5630	−18.46	−18.47	0.01		
	1414	5639	−18.45	−18.52	0.07		
	1416.5	5641.5	−18.46	−18.52	0.06		
	1419	5644	−18.45	−18.46	0.01		
	1421	5646	−18.47	−18.55	0.08		
	1425	5650	−18.46	−18.51	0.05		
	1428	5653	−18.46	−18.53	0.07		
	1432	5657	−18.47	−18.54	0.07		
	1436	5661	−18.46	−18.52	0.06		
	1440	5665	−18.47	−18.54	0.07		
	1625	5770	−18.46	−18.54	0.08		
	2000	5985	−18.41	−18.56	0.15		
18–Jul–93	733	6678	−18.53	−18.79	0.26		
	1119	6904	−18.53	−18.8	0.27		
	1405	7070	−18.52	−18.82	0.30		
	1735	7280	−18.52	−18.81	0.29		
19–Jul–93	841	8186	−18.59	−18.95	0.36		
	1515	8580	−18.57	−18.89	0.32		
	1940	8845	−18.5	−18.84	[illegible]		

APPENDIX D.3

Phase III Testing
April 1994

APPENDIX E

Treatability Study Analysis

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APPENDIX E.1

Hydrocarbon Removal by Physical Processes

09/08/93	F	1600	1600		114.0748	24	68	1651
09/09/93	F	1100	1100		112.1794	24	46	1697
09/10/93	F	1000	1000		105.1399	24	39	1736
09/11/93	F	820	820		111.9953	24	34	1771
09/12/93	F	28	28		104.9413	16	1	1771
09/13/93	F	650	650		104.7258	12	13	1784
09/14/93	F	746	746		112.069	14	18	1802
09/15/93	F	620	620		96.5948	12	11	1814
09/16/93	F	500	500		95.77559	10	7	1821
09/17/93	F	350	350		89.00049	10	5	1826
09/18/93	F	350	350		89.92576	15	7	1833
09/19/93	F	160	160		99.67255	9	2	1835
09/20/93	F	28	28		88.12213	12	0	1836
09/21/93	F	180	180		83.19278	12	3	1839
09/22/93	F	290	290		81.34625	12	4	1843
09/23/93	F	110	110		103.8007	12	2	1845
09/24/93	F	230	230		101.931	24	9	1854
09/25/93	F	220	220		144.2678	24	12	1866
09/26/93	F	180	180		117.6248	12	4	1870
09/27/93	F	210	210		116.3319	12	5	1874
09/28/93	F	240	240		136.7314	24	12	1887
09/29/93	F	300	300		129.5988	24	15	1901
09/30/93	F	120	120		134.3545	24	6	1907
10/01/93	F	240	240		133.2364	24	12	1919
10/02/93	L	178	178		126.2832	16	6	1925
10/03/93	F	260	260		144.3183	12	7	1932
10/04/93	F	445	445		127.928	20	18	1950
10/05/93	F	360	360		116.7333	14	9	1959
10/06/93			380	E	116.7	2	1	1960
10/07/93					0	0	0	1960
10/08/93	F	400	400		159.4298	15	15	1975
10/09/93	F	450	450		135.2762	24	23	1998
10/10/93	F	450	450		138.2853	24	23	2021
10/11/93	F	400	400		142.0843	12	11	2032
10/12/93	F	800	800		145.7314	12	22	2053
10/13/93	F	1300	1300		141.7845	24	69	2122
10/14/93	F	420	420		126.9311	24	20	2142
10/15/93			1210		140.2545	24	63	2206
10/16/93	F	2000	2000		148.0909	24	111	2316
10/17/93	F	1600	1600		139.634	24	83	2400
10/18/93	F	2200	2200		139.634	24	115	2514
10/19/93	F	2400	2400		141.0138	24	126	2641

10/20/93	F	2600	2600	140.0914	24	136	2777
10/21/93	F	3500	3500	128.95	24	169	2946
10/22/93	F	2800	2800	129.1833	24	135	3081
10/23/93	F	3200	3200	141.6461	24	169	3250
10/24/93	F	3400	3400	147.6048	24	187	3437
10/25/93	F	3600	3600	140.5207	24	189	3626
10/26/93	F	4000	4000	140.899	24	211	3837
10/27/93	F	4000	4000	139.7014	24	209	4046
10/28/93	F	6000	6000	127.4679	12	143	4189
10/29/93	F	6000	6000	127.1134	12	142	4331
10/30/93	F	2800	2800	126.5759	24	132	4464
10/31/93	F	1800	1800	99.50238	24	67	4530
11/01/93	F	800	800	116.6577	16	23	4554
11/02/93	F	5700	5700	114.4988	12	122	4676
11/03/93	L	6510	6510	152.4432	24	371	5046
11/04/93	F	4800	4800	151.0841	21	237	5283
11/05/93	F	5000	5000	140.3627	24	262	5546
11/06/93	F	4600	4600	149.4197	24	257	5802
11/07/93	F	4800	4800	150.7815	24	270	6073
11/08/93	F	4600	4600	150.7815	24	259	6332
11/09/93	F	4600	4600	149.4372	24	257	6589
11/10/93	F	4400	4400	150.4542	24	247	6836
11/11/93	F	450	450	149.4372	24	25	6861
11/12/93	F	4200	4200	149.1371	24	234	7095
11/13/93	F	4600	4600	149.1397	24	256	7352
11/14/93	F	4500	4500	149.6334	24	252	7603
11/15/93	F	4600	4600	145.4219	24	250	7853
11/16/93	F	4400	4400	150.7815	24	248	8101
11/17/93	F	4600	4600	151.0003	24	260	8360
11/18/93	F	4600	4600	139.702	24	240	8600
11/19/93	F	4400	4400	145.246	24	239	8839
11/20/93	F	4200	4200	145.8023	24	229	9068
11/21/93	F	4300	4300	149.404	24	240	9308
11/22/93	F	520	520	149.3747	12	15	9323
11/23/93	F	4500	4500	150.8715	24	254	9576
11/24/93	F	3800	3800	149.9553	24	213	9789
11/25/93	F	2050	2050	139.992	24	107	9896
11/26/93	F	300	300	128.9945	8	5	9901
11/27/93	F	400	400	141.5643	9	8	9909
11/28/93	F	230	230	149.621	10	5	9914
11/29/93	F	2215	2215	138.7196	21	100	10015
11/30/93	F	2215	2215	138.7196	18	86	10101

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12/01/93	F	2215	2215		136.2966	0	0	10101
12/02/93			2215	E	132	8	36	10137
12/03/93	F	4200	4200		127.7394	20	167	10304
12/04/93	F	4200	4200		127.8395	24	201	10505
12/05/93	F	4200	4200		125.0913	24	196	10701
12/06/93			4000	E	130.9	13	106	10807
12/07/93	F	3800	3800		136.7941	24	194	11001
12/08/93	L	5430	5430		132.6469	24	269	11271
12/09/93	F	4400	4400		138.9637	20	190	11461
12/10/93	F	4400	4400		138.0267	24	227	11688
12/11/93	F	4800	4800		127.3578	17	162	11850
12/12/93	F	4800	4800		137.8461	24	247	12097
12/13/93	F	5100	5100		127.2461	24	242	12339
12/14/93	F	4800	4800		127.4332	24	229	12568
12/15/93	F	4600	4600		127.4332	24	219	12787
12/16/93	F	4600	4600		127.3917	24	219	13006
12/17/93		0	3800		140.6025	24	200	13205
12/18/93	F	3000	3000		133.1538	24	149	13354
12/19/93	F	3000	3000		125.5272	24	141	13495
12/20/93	F	2750	2750		125.9018	24	129	13625
12/21/93	F	2500	2500		126.3182	24	118	13743
12/22/93	F	2750	2750		126.2144	24	130	13872
12/23/93	F	3000	3000		126.3613	24	142	14014
12/24/93	F	3000	3000		126.629	24	142	14156
12/25/93	F	3000	3000		126.629	24	142	14298
12/26/93	F	3000	3000		126.629	24	142	14440
12/27/93	F	3000	3000		126.629	24	142	14582
12/28/93	F	3000	3000		127.0601	24	142	14724
12/29/93	F	3000	3000		126.629	24	142	14866
12/30/93	F	3000	3000		126.629	24	142	15008
12/31/93	F	3000	3000		126.629	24	142	15150
01/01/94	F	3000	3000		126.629	24	142	15292
01/02/94	F	3000	3000		126.629	24	142	15434
01/03/94	F	3000	3000		126.629	24	142	15575
01/04/94	F	3000	3000		126.629	24	142	15717
01/05/94	F	3000	3000		124.4247	24	139	15857
01/06/94		0	2410	E	125	6	28	15885
01/07/94		0	2410		0	0	0	15885
01/08/94		0	2410		0	0	0	15885
01/09/94	L	1810	1810		115.1728	0	0	15885
01/10/94	F	550	550		128.2147	12	13	15898
01/11/94	F	4200	4200		128.4257	24	202	16100

01/12/94	F	4200	4200		128.1995	24	201	16301
01/13/94	F	4300	4300		128.5606	24	207	16507
01/14/94	F	4200	4200		128.4159	24	201	16709
01/15/94	F	4200	4200		128.5606	24	202	16911
01/16/94	F	4350	4350		128.576	24	209	17120
01/17/94	F	4200	4200		128.4315	24	202	17321
01/18/94	F	4300	4300		128.6334	24	207	17528
01/19/94	F	4250	4250		128.4159	24	204	17732
01/20/94	F	4250	4250		128.2917	24	204	17935
01/21/94	F	4300	4300		140.6952	24	226	18161
01/22/94	F	4300	4300		128.5399	24	206	18368
01/23/94	F	4250	4250		128.3696	24	204	18572
01/24/94	F	4250	4250		128.4159	24	204	18776
01/25/94	F	4300	4300		128.1007	24	206	18981
01/26/94	F	4250	4250		127.5234	24	202	19184
01/27/94	F	4250	4250		139.7365	24	222	19406
01/28/94	F	4300	4300		128.1007	24	206	19611
01/29/94	F	4300	4300		127.6747	24	205	19817
01/30/94	F	4300	4300		127.7121	24	205	20022
01/31/94		0	4330		128.7425	12	104	20126
02/01/94	F	4350	4350		128.6334	24	209	20335
02/02/94	F	4300	4300		128.6955	24	207	20542
02/03/94	F	4350	4350		128.9497	24	210	20751
02/04/94	F	4350	4350		129.3976	24	210	20962
02/05/94	F	3600	3600		139.9617	10	78	21040
02/06/94	L	4640	4640		131.3802	23	218	21258
02/07/94		0	3820	E	131	5	39	21297
02/08/94		0	3820		0	0	0	21297
02/09/94		0	3820		0	0	0	21297
02/10/94	F	3000	3000		125.4747	9	53	21350

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HC Removal Rates for the West SVE System

Date		THC Concentration ppmv	Assumed Concentration ppmv		Flow Rate scfm	Operation hr	THC Removed lb/day	Cummulative HC Removed lb
08/03/93	L	28900	28900	E	126.5	18	1024	1024
08/04/93			23675		126.6827	23	1074	2098
08/05/93			23675		126.4591	24	1119	3217
08/06/93			23675		126.5943	24	1120	4336
08/07/93			23675		126.8121	24	1122	5458
08/08/93			23675		126.5411	24	1119	6577
08/09/93	L	18450	18450		126.6149	24	873	7450
08/10/93			19675		126.1508	24	927	8377
08/11/93			19675		126.0901	24	927	9304
08/12/93			19675		126.4694	24	930	10234
08/13/93			19675		126.384	24	929	11163
08/14/93			19675		119.0516	24	875	12038
08/15/93			19675		119.887	24	881	12919
08/16/93			19675		126.2841	24	928	13847
08/17/93			19675		126.2307	24	928	14775
08/18/93	F	10000	19675		125.5747	24	923	15698
08/19/93	L	20900	20900		125.6471	24	981	16679
08/20/93	F	10000	19700		125.8489	24	926	17606
08/21/93	F	10000	19700		132.7508	22	896	18501
08/22/93	F	10000	19700		127.5468	24	939	19440
08/23/93	F	10000	19700		134.2431	20	823	20263
08/24/93	F	10000	19700		128.7954	22	869	21132
08/25/93	F	10000	19700		134.6782	24	991	22123
08/26/93	F	10000	19700		133.6966	24	984	23107
08/27/93	F	10000	19700		138.9597	21	895	24002
08/28/93	F	10000	19700		133.2991	24	981	24983
08/29/93	F	10000	19700		127.1144	24	936	25919
08/30/93	F	10000	19700		138.9139	24	1022	26941
08/31/93	F	10000	19700		131.8441	24	970	27912
09/01/93	L	18500	18500		131.5119	21	795	28707
09/02/93			19150		139.1457	24	996	29703
09/03/93	L	19800	19800		140.2684	24	1038	30740
09/04/93	F	10000	14500		140.6499	24	762	31502
09/05/93	F	10000	14500		139.0293	24	753	32255
09/06/93			14500		138.127	24	748	33003
09/07/93	F	10000	14500		138.6741	24	751	33755

09/08/93	F	10000	14500		140.7759	24	763	34517
09/09/93	F	10000	14500		139.019	24	753	35270
09/10/93	F	10000	14500		135.0297	24	731	36002
09/11/93	F	10000	14500		138.7898	24	752	36754
09/12/93	F	10000	14500		132.6895	24	719	37473
09/13/93	F	10000	14500		133.6414	24	724	38196
09/14/93	F	10000	14500		138.8938	24	752	38949
09/15/93	F	10000	14500		126.2784	24	684	39633
09/16/93	F	10000	14500		125.5697	24	680	40313
09/17/93	F	10000	14500		120.6419	24	654	40967
09/18/93	F	10000	14500		128.0165	24	693	41660
09/19/93	F	9200	9200		151.9407	24	522	42182
09/20/93	F	9050	9050		147.1308	24	497	42680
09/21/93	F	7000	7000		140.2836	24	367	43047
09/22/93	F	10000	6900		128.5259	24	331	43378
09/23/93	F	10000	6900		113.5433	24	293	43671
09/24/93	F	10000	6900		113.5064	24	293	43963
09/25/93	F	10000	6900		112.9991	24	291	44255
09/26/93	F	10000	6900		114.8381	24	296	44551
09/27/93	F	6800	6800		143.3342	12	182	44733
09/28/93	F	10000	10250		136.198	24	522	45254
09/29/93	F	10000	10250		114.615	20	366	45620
09/30/93	F	10000	10250		112.7161	24	432	46052
10/01/93	F	10000	10250		123.8194	24	474	46526
10/02/93	L	13700	13700		124.5024	16	425	46951
10/03/93	F	10000	16300		126.9122	12	386	47337
10/04/93	F	10000	16300		126.1958	20	640	47978
10/05/93	F	10000	16300		123.5501	14	439	48416
10/06/93			16300	E	124.3	2	63	48480
10/07/93			16300		0	0	0	48480
10/08/93	F	10000	16300		136.9003	15	521	49001
10/09/93	F	10000	16300		127.0841	24	774	49774
10/10/93	F	10000	16300		125.1791	24	762	50537
10/11/93	F	10000	16300		127.0841	24	774	51311
10/12/93	F	10000	16300		126.0066	24	767	52078
10/13/93	F	10000	16300		138.9828	24	846	52924
10/14/93	F	10000	16300		135.9947	24	828	53753
10/15/93			16300		127.1807	24	774	54527
10/16/93	F	10000	16300		128.2917	24	781	55308
10/17/93	F	10000	16300		127.0379	24	774	56082
10/18/93	F	10000	16300		127.4679	24	776	56858
10/19/93	F	10000	16300		128.509	24	783	57641

10/20/93	F	10000	16300	127.8853	24	779	58420
10/21/93	F	10000	16300	128.0727	24	780	59199
10/22/93	F	10000	16300	128.184	24	781	59980
10/23/93	F	10000	16300	128.7499	24	784	60764
10/24/93	F	10000	16300	137.3259	24	836	61600
10/25/93	F	10000	16300	128.2773	24	781	62381
10/26/93	F	10000	16300	129.3898	24	788	63169
10/27/93	F	10000	16300	139.0104	24	847	64016
10/28/93	F	10000	16300	139.8666	12	426	64442
10/29/93	F	10000	16300	139.9425	12	426	64868
10/30/93	F	10000	16300	126.9957	24	773	65641
10/31/93	F	10000	16300	127.2721	24	775	66416
11/01/93	F	10000	16300	127.5506	16	518	66934
11/02/93	F	10000	16300	127.7986	24	778	67712
11/03/93	L	18900	18900	127.9551	24	903	68616
11/04/93	F	10000	19550	128.9696	19	746	69362
11/05/93	F	10000	19550	127.598	23	893	70255
11/06/93	F	10000	19550	138.5631	24	1012	71267
11/07/93	F	10000	19550	127.6465	24	932	72199
11/08/93	F	10000	19550	127.8605	24	934	73133
11/09/93	F	10000	19550	126.2975	24	922	74055
11/10/93	F	10000	19550	126.1035	24	921	74977
11/11/93	F	10000	19550	125.8786	24	919	75896
11/12/93	F	10000	19550	124.4069	24	909	76805
11/13/93	F	10000	19550	126.4669	24	924	77728
11/14/93	F	10000	19550	126.887	24	927	78655
11/15/93	F	10000	19550	127.9722	24	935	79590
11/16/93	F	10000	19550	128.509	24	939	80528
11/17/93	F	10000	19550	128.2615	24	937	81465
11/18/93	F	10000	19550	127.5299	24	931	82397
11/19/93	F	10000	19550	127.9224	24	934	83331
11/20/93	F	10000	19550	128.5191	24	939	84270
11/21/93	F	10000	19550	127.0063	24	928	85197
11/22/93	F	10000	19550	125.6263	24	918	86115
11/23/93	F	10000	19550	127.7263	24	933	87048
11/24/93	F	10000	19550	127.3654	24	930	87978
11/25/93	F	10000	19550	127.2628	24	930	88907
11/26/93	F	10000	19550	127.1601	24	929	89836
11/27/93	F	10000	19550	127.2833	24	930	90766
11/28/93	F	10000	19550	126.0375	24	921	91686
11/29/93	F	10000	19550	131.609	24	961	92648
11/30/93	F	10000	19550	131.609	24	961	93609

12/01/93	F	10000	19550		131.609	24	961	94570
12/02/93	F	10000	19550		136.9411	24	1000	95570
12/03/93	F	10000	19550		127.5234	24	931	96502
12/04/93	F	10000	19550		127.6238	24	932	97434
12/05/93	F	10000	19550		127.1062	24	928	98362
12/06/93	F	10000	19550		126.0293	24	921	99283
12/07/93	F	11000	19550		125.2965	24	915	100198
12/08/93	L	20200	20200		127.443	24	962	101160
12/09/93	F	10000	20250		127.625	20	805	101964
12/10/93	F	10000	20250		127.9146	24	968	102932
12/11/93	F	10000	20250		126.934	17	680	103612
12/12/93	F	10000	20250		137.3934	24	1039	104652
12/13/93	F	10000	20250		124.4036	24	941	105593
12/14/93		0	20250	E	131.5	24	995	106588
12/15/93		0	20250	E	131.5	2	83	106671
12/16/93	F	11000	20250		138.6202	4	175	106845
12/17/93	F	10000	20250		127.0532	24	961	107807
12/18/93	F	10000	20250		126.8503	24	960	108766
12/19/93	F	10000	20250		126.4777	24	957	109723
12/20/93	F	10000	20250		126.535	24	957	110680
12/21/93	F	10000	20250		126.5293	24	957	111638
12/22/93	F	10000	20250		126.4253	24	956	112594
12/23/93	F	10000	20250		126.4669	24	957	113551
12/24/93	F	10000	20250		126.629	24	958	114509
12/25/93	F	10000	20250		126.629	24	958	115467
12/26/93	F	10000	20250		126.629	24	958	116425
12/27/93	F	10000	20250		126.629	24	958	117383
12/28/93	F	10000	20250		127.166	24	962	118345
12/29/93	F	10000	20250		126.629	24	958	119303
12/30/93	F	10000	20250		126.629	24	958	120261
12/31/93	F	10000	20250		126.629	24	958	121219
01/01/94	F	10000	20250		126.629	24	958	122177
01/02/94	F	10000	20250		126.629	24	958	123135
01/03/94	F	10000	20250		126.629	24	958	124093
01/04/94	F	10000	20250		126.629	24	958	125051
01/05/94	F	10000	20250		124.4247	24	941	125992
01/06/94		0	20250		124	6	235	126227
01/07/94		0	20250		0	0	0	126227
01/08/94		0	20250		0	0	0	126227
01/09/94	L	7800	20300		128.0962	15	607	126834
01/10/94	F	10000	19500		138.4699	24	1009	127843
01/11/94	F	10000	19500		145.3162	24	1059	128901

01/12/94	F	10000	19500		145.3162	24	1059	129960
01/13/94	F	10000	19500		152.115	24	1108	131068
01/14/94	F	10000	19500		151.9437	24	1107	132175
01/15/94	F	10000	19500		151.9866	24	1107	133282
01/16/94	F	10000	19500		152.1331	24	1108	134391
01/17/94	F	10000	19500		162.3176	24	1183	135573
01/18/94	F	10000	19500		162.2977	24	1182	136756
01/19/94	F	10000	19500		151.6877	24	1105	137861
01/20/94	F	10000	19500		162.0042	24	1180	139041
01/21/94	F	10000	19500		162.1871	24	1182	140222
01/22/94	F	10000	19500		140.6897	24	1025	141247
01/23/94	F	10000	19500		151.8889	24	1107	142354
01/24/94	F	10000	19500		151.8156	24	1106	143460
01/25/94	F	10000	19500		140.3273	24	1022	144482
01/26/94	F	10000	19500		139.5771	24	1017	145499
01/27/94	F	10000	19500		139.6189	24	1017	146516
01/28/94	F	10000	19500		140.2092	24	1021	147538
01/29/94	F	10000	19500		150.9401	24	1100	148637
01/30/94	F	10000	19500		150.9846	24	1100	149737
01/31/94	F	10000	19500		150.8018	24	1099	150836
02/01/94	F	10000	19500		150.8018	24	1099	151935
02/02/94	F	10000	19500		151.0003	24	1100	153035
02/03/94	F	10000	19500		140.1903	24	1021	154056
02/04/94	F	10000	19500		140.7966	24	1026	155082
02/05/94	F	10000	19500		140.5319	10	427	155508
02/06/94	L	18800	18800		136.8815	23	921	156430
02/07/94	F	0	18890	E	137	5	201	156631
02/08/94	F	0	18890		0	0	0	156631
02/09/94	F	0	18890		0	0	0	156631
02/10/94	L	18975	19000		137.4507	16	650	157281

APPENDIX E.2

Heat Balance Calculations

RADIAN
CORPORATION

CALCULATION SHEET

CALC. NO. ______

SIGNATURE Whitney Delaney DATE 4/28/94 CHECKED JC DATE 5/12/94

PROJECT Galena TS JOB NO. ______

SUBJECT Theoretical Temperature Rise in Soils from Heptane Oxidation SHEET 1 OF 2 SHEETS

Average biodegradation rate in active areas
3.2 mg heptane / kg soil / day
from Phase II respiration tests

$$Q = m C_p \Delta T$$

Q = heat generated during oxidation
m = mass soil
C_p = heat capacity of soil
ΔT = temperature change

$$Q = \frac{3.2 \text{ mg heptane}}{\text{kg soil day}} \cdot \frac{4854 \text{ kJ}}{\text{mol heptane}} \cdot \frac{1 \text{ mol heptane}}{100{,}000 \text{ mg heptane}}$$

(~~oxidatn~~ heat released during combustion)

$$= 0.155 \frac{\text{kJ}}{\text{kg soil day}}$$

$$C_{p_{soil}} = 0.345 \frac{\text{cal}}{\text{cm}^3 \, ^\circ\text{C}}$$

(Carslaw, 1959)

$$C_p = 0.345 \frac{\text{cal}}{\text{cm}^3 \, ^\circ\text{C}} \cdot \frac{\text{ft}^3}{50 \text{ kg}} \cdot \frac{1728 \text{ in}^3}{\text{ft}^3} \cdot 16.39 \frac{\text{cm}^3}{\text{in}^3} \cdot \frac{\text{kcal}}{1000 \text{ cal}}$$

$$= 0.195 \frac{\text{kcal}}{\text{kg soil} \, ^\circ\text{C}}$$

$$Q = m C_p \Delta T \Longrightarrow \Delta T = \frac{Q}{m C_p} \qquad Q \frac{1}{m} \frac{1}{C_p}$$

$$\Delta T = \frac{0.155 \text{ kJ}}{\text{kg soil day}} \cdot \frac{\text{kg soil} \, ^\circ\text{C}}{0.195 \text{ kcal}} \cdot \cancel{\frac{4.184 \text{ kJ}}{\text{kcal}}} \; \frac{\text{kcal}}{4.184 \text{ kJ}}$$

$$= \overset{0.19}{\cancel{3.3}} \; ^\circ\text{C} / \text{day}$$

RADIAN
CORPORATION

CALCULATION SHEET

CALC. NO.

SIGNATURE DATE CHECKED FJC DATE 5/12/94

PROJECT JOB NO.

SUBJECT Theoretical Temperature Rise SHEET 2 OF 2 SHEETS

Test period = 180 days

$$\Delta T_{test} = \frac{0.19\ ^\circ C}{day} \cdot 180 \text{ days} = 34\ ^\circ C$$

This assumes ~~not~~ no heat loss to the surroundings or insulation effects of the snow cover.

This is strictly the temperature rise ~~from~~ in soil with a specified heat capacity based on the heat generated from the oxidation (biological in nature) of heptane.

RADIAN CORPORATION

CALCULATION SHEET

CALC. NO.

SIGNATURE DATE 4/18/94 CHECKED JC DATE 5/12/94

PROJECT Galena TS JOB NO.

SUBJECT Heat Generation and Transfer SHEET 1 OF 3 SHEETS

Source: Carslaw, H.S. and J.C. Jaeger. Conduction of Heat in Solids, 2nd ed. Oxford University Press, New York, 1959, pg. 224.

For a finite cylinder $0 < z < l$, $0 \leq r < a$ with constant heat generation rate A_0 per unit time per unit volume, the above source gives the following heat conduction equation:

$$(1) \quad \frac{\partial^2 v}{\partial r^2} + \frac{1}{r}\frac{\partial v}{\partial r} + \frac{\partial^2 v}{\partial z^2} = -\frac{A_0}{K}$$

where v = temperature, °C
r = radial distance from axis, m
z = axial distance from base, m
A_0 = heat generation constant, kcal/m³ hr
K = thermal conductivity, kcal/cm sec °C

Given the following boundary conditions:

$$(2) \quad \left.\begin{matrix} z = 0 \\ z = l \\ r = a \end{matrix}\right\} v = 0$$

The solution to (1) given (2) is:

$$(3) \quad v = \frac{A_0 z(l-z)}{2K} - \frac{4l^2 A_0}{K\pi^3} \sum_{n=0}^{\infty} \frac{I_0\left[\frac{(2n+1)\pi r}{l}\right]}{(2n+1)^3 I_0\left[\frac{(2n+1)\pi a}{l}\right]} \sin\frac{(2n+1)\pi z}{l}$$

where $I_0(x)$ = hyperbolic Bessel function

CALCULATION SHEET

CALC. NO.

SIGNATURE DATE CHECKED FJC DATE 5/12/94

PROJECT JOB NO.

SUBJECT SHEET 2 OF 3 SHEETS

In order to apply this solution to the pilot study at Galena AFS, the following assumptions were made:

- $A_o = 0.035$ kcal/kg day (from the average oxidation rate for heptane)
- $K = 4.35 \times 10^{-3}$ cal/cm sec °C (for wet sand)
- $a = 50$ ft (See contours on figure ⓘ?)
- $l = 20$ ft
- ρ = bulk density = 50 kg/ft³

Making unit conversions;

$$A_0 = \left(0.035 \, \frac{\text{kcal}}{\text{kg day}}\right)\left(50 \, \frac{\text{kg}}{\text{ft}^3}\right)\left(\frac{1 \text{ day}}{24 \text{ hr}}\right)\left(\frac{1 \text{ hr}}{3600 \text{ sec}}\right) = 2.03 \times 10^{-5} \, \frac{\text{kcal}}{\text{ft}^3 \text{ sec}}$$

A computer program was used to evaluate equation (3) given the above input values. The results are tabulated below:

r (ft)	z (ft)	v (°C)
0	10	7.8
30	10	7.4
40	10	6.0
45	10	4.0
47.5	10	2.3
50	10	0

CALCULATION SHEET

CALC. NO.

SIGNATURE DATE CHECKED JC DATE 5/12/94

PROJECT JOB NO.

SUBJECT SHEET 3 OF 3 SHEETS

Because the maximum observed temperature is 40°C, the value for A_0 will be increased to find a temperature distribution that better fits the observed data.

For a value of $A_0 = 0.39 \text{ kcal/ft}^3\text{hr}$, the following results are tabulated:

r(ft)	z(ft)	v(°C)
0	10	40.7
30	10	38.5
40	10	31.0
45	10	20.7
47.5	10	12.1
50	10	0

Comparing the volumetric heating rate derived from the oxidation of heptane to the one required to give the observed temperature distribution gives:

$$\text{ratio} = \frac{0.39 \text{ kcal/ft}^3\text{hr}}{\left(2.03\times10^{-5} \text{ kcal/ft}^3\text{sec}\right)\left(\frac{3600\text{sec}}{(1\text{ hr})}\right)} \approx 5$$

∴ Five times more heat would be required to give the observed temperature distribution than can be accounted for by the oxidation of heptane.

APPENDIX E.3

Hydrocarbon Removal by Biological Processes

RADIAN CORPORATION

CALCULATION SHEET

CALC. NO.

SIGNATURE Whitney Dulaney DATE 5/9/94 CHECKED J. Rehage DATE 5/11/94

PROJECT Galena Airport TS JOB NO.

SUBJECT Mass Biodegraded During Phase II test SHEET 1 OF 2 SHEETS

Study Area	Estimated Avg. Biodegradation Rate (mg/kg/day)	
West Cell	3.2	V-1 thru V-4 - most active area
East Cell	0.2	

West Cell

Assume 75-ft radius of biological activity centered on the western portion of the West Cell.

SVE known to have 150-ft radius of influence so 75-ft radius circle is aerated by SVE System.

Assume this area has hydrocarbon concentrations high enough to support biological activity. Also assume degradation is constant over area.

Water table fluctuations during test period:

8/2 130 ft msl
2/10 122 ft msl] average 126 ft msl

Ground level elevation : 147 ft msl in West Cell

Average vadose-zone thickness : 147 - 126 = 21 ft

Volume of soil within Biologically-Active Area =

$\pi r^2 \times \text{depth} = \pi (75)^2 (21) = 371,000 \text{ ft}^3$

RADIAN
CORPORATION

CALCULATION SHEET

CALC. NO.

SIGNATURE A Whitney Delaney DATE
CHECKED J. Rehage DATE 5/11/94

PROJECT Galena Airport FS
JOB NO.

SUBJECT Mass Biodegraded
SHEET 2 OF 2 SHEETS

Mass of Hydrocarbons Biodegraded :

$$\frac{3.2\text{ mg heptane}}{\text{kg soil}\cdot\text{day}}\cdot\frac{\text{lb}}{454000\text{ mg}}\cdot\frac{50\text{ kg soil}}{\text{ft}^3}\cdot 371{,}000\text{ ft}^3\cdot 180\text{ day}$$

$\approx$ 23,500 lb hydrocarbons as heptane

East Cell

East Cell is significantly less contaminated than the West Cell

∴ assume the radial extent of biological activity is ~~at~~ a 50-ft radius centered toward the western portion of the East Cell.

Avg. ~~GW~~ Ground Level elevation : 145 ft MSL in the East Cell

Average vadose-zone thickness : 145 − 126 = 19 ft

Volume of soil within biologically-active area =

$$\pi r^2 \times \text{depth} = \pi(50)^2\, 19 = 149{,}000\text{ ft}^3$$

Mass of Hydrocarbons Biodegraded :

$$\frac{0.2\text{ mg heptane}}{\text{kg soil}\cdot\text{day}}\cdot\frac{\text{lb}}{454000\text{ mg}}\cdot\frac{50\text{ kg soil}}{\text{ft}^3}\cdot 149{,}000\text{ ft}^3\cdot 180\text{ day}$$

$\approx$ 590 lb hydrocarbons

References

Carslaw, H.S. and J.C. Jaeger. *Conduction of Heat in Solids*, 2nd ed. New York: Oxford University Press, 1959.