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SITE-SPECIFIC TECHNICAL REPORT FOR FREE PRODUCT RECOVERY TESTING AT SITE SS-06, WURTSMITH AFB, MICHIGAN

DRAFT

PREPARED FOR:

AIR FORCE CENTER FOR ENVIRONMENTAL EXCELLENCE
TECHNOLOGY TRANSFER DIVISION
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24 MARCH 1997

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SITE-SPECIFIC TECHNICAL REPORT (A003)

for

FREE PRODUCT RECOVERY TESTING AT SITE SS-06, WURTSMITH AFB, MICHIGAN

by

A. Leeson, M. Place, and L. Cumming

for

Mr. Patrick Haas
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Brooks AFB, Texas 78235-5357

24 March 1997

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505 King Avenue
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ACRONYMS AND ABBREVIATIONS

AFB	Air Force Base
AFCEE	U.S. Air Force Center for Environmental Excellence
bgs	below ground surface
BTEX	benzene, toluene, ethylbenzene, and xylenes
ft/ft	foot per foot
HC1	hydrochloric acid
LNAPL	light-nonaqueous-phase liquid
MW	monitoring well
POL	petroleum, oils, and lubricants
ppmv	part(s) per million by volume
PVC	polyvinyl chloride
scfm	standard cubic foot (feet) per minute
TPH	total petroleum hydrocarbon
VOC	volatile organic compound

EXECUTIVE SUMMARY

This report summarizes the field activities conducted at Wurtsmith Air Force Base (AFB) for a short-term field pilot test to compare vacuum-enhanced free-product recovery (bioslurping) to traditional free-product recovery techniques used to remove light, nonaqueous-phase liquid (LNAPL) from subsurface soils and aquifers. The field testing at Wurtsmith AFB is part of the Bioslurper Initiative, which is funded and managed by the U.S. Air Force Center for Environmental Excellence (AFCEE) Technology Transfer Division. The AFCEE Bioslurper initiative is a multisite program designed to evaluate the efficacy of the bioslurping technology for (1) recovery of LNAPL from groundwater and the capillary fringe, and (2) enhancing natural in situ degradation of petroleum contaminants in the vadose zone via bioventing.

The main objective of the Bioslurper Initiative is to develop procedures for evaluating the potential for recovering free-phase LNAPL present at petroleum-contaminated sites. The overall study is designed to evaluate bioslurping and identify site parameters that are reliable predictors of bioslurping performance. To measure LNAPL recovery in a wide variety of in situ conditions, tests are being performed at many sites. The test at Wurtsmith is one of more than 40 similar field tests to be conducted at various locations throughout the United States and its possessions.

The intent of field testing is to collect data to support determination of the predictability of LNAPL recovery and to evaluate the applicability, cost, and performance of the bioslurping technology for removal of free product and remediation of the contaminated area. The on-site testing is structured to allow direct comparison of the LNAPL recovery achieved by bioslurping with the performance of more conventional LNAPL recovery technologies. The test method included an initial site characterization followed by LNAPL recovery testing. The three LNAPL recovery technologies tested at Wurtsmith AFB were skimmer pumping, bioslurping, and drawdown pumping.

Bioslurper pilot test activities were conducted at two monitoring wells at : (1) monitoring well H192S, and (2) monitoring well H196S. Site characterization activities were conducted to evaluate site variables that could affect LNAPL recovery efficiency and to determine the bioventing potential of the site. Testing included baildown testing to evaluate the mobility of LNAPL, soil sampling to determine physical/chemical site characteristics, soil gas permeability testing to determine the radius of influence, and in situ respiration testing to evaluate site microbial activity.

Following the site characterization activities, the pump tests were conducted. At monitoring well H192S, pilot tests for skimmer pumping, bioslurping, and drawdown pumping were conducted.

The LNAPL recovery testing was conducted in the following sequence at monitoring well H192S: 48 hr in the skimmer configuration, 95 hr in the bioslurper configuration, an additional 23 hr in the skimmer configuration, and 25 hr in the drawdown configuration.

After the drawdown pump test at H192S, LNAPL recovery testing was conducted at monitoring well H196S for 14 hr in the bioslurper configuration.

Measurements of extracted soil gas composition, LNAPL thickness, and groundwater level were taken throughout the testing. The volume of LNAPL recovered and groundwater extracted were quantified over time.

Baildown recovery tests were conducted at monitoring wells H196S and H192S. Baildown recovery tests provide a qualitative indication of the presence of mobile, free-phase LNAPL and recovery potential. Overall, the baildown recovery tests indicated a moderate rate of LNAPL recovery into the wells. At monitoring well H192S, LNAPL recovered to approximate initial levels by the end of the 28 hr baildown test. At monitoring well H196S, LNAPL recovered to a level approximately ⅓ of the initial LNAPL thickness. Based on these results, pilot testing was initiated on monitoring well H192S.

Direct pumping tests were conducted at monitoring wells H192S and H196S. Skimmer pump testing was conducted at monitoring well H192S in a continuous extraction mode for two days. Minimal quantities of free-phase LNAPL was recovered during the two days of skimmer pump testing, indicating that gravity-driven recovery is minimal. Bioslurper testing was conducted for four days resulting in relatively low recovery on the first day (2.3 gallons/day), followed by steadily dropping recovery rates. The LNAPL recovery rate dropped to 0.40 gallons/day by hour 63. At this point, the pump vacuum was increased to full vacuum, and a slight increase in LNAPL recover was observed (0.71 gallons/da); however, recovery dropped to 0 by day 4. The loss of LNAPL recovery is likely due to the drop in the vapor extraction rate. Groundwater production rates during bioslurping were higher than rates during the drawdown pump test, indicating that vacuum enhanced fluid recovery was in effect during the bioslurper pump test. The on-site water treatment equipment, consisting of a filter tank, oil/water separator, and clarification tanks, resulted in water effluent (2.2 to 9.6 mg/L total hydrocarbons) that is considered compatible with typical sanitary sewer discharge limits.

Drawdown testing was conducted to determine if a cone of groundwater depression would enhance LNAPL recovery. The water table was depressed in monitoring well H192S 5 inches below the static water table. No measurable LNAPL free product was recovered in this mode during one day of continuous extraction. Groundwater recovery rates were on the order of 1,900 gallons/day. Based on these results, the vacuum gradient maintained during the bioslurper pump test resulted in higher fluid recovery rates than the 5 inch-groundwater drawdown test.

In an effort to determine if the results at monitoring well H192S were representative of site conditions, bioslurper testing was conducted at monitoring well H196S. Minimal free-phase LNAPL was recovered during the half day of bioslurper pumping (2.2 gallons/day). The well head vacuum on monitoring well H196S (2.5"H_2O) and groundwater production rate (5,000 gallons/day) were similar to those observed at monitoring well H192S. Results at monitoring wells H192S and H196S appear to be representative of the site and indicate that gravity-driven liquid recovery techniques are not feasible and that vacuum-enhanced recovery is minimal.

Bioslurping also promotes mass removal in the form of in situ biodegradation via bioventing and soil gas extraction. Vapor phase mass removal is the result of soil gas extraction as well as volatilization that occurs during the movement of LNAPL free product through the extraction network. Given, the measured vapor flowrate (2 L/min) and vapor concentrations, initial hydrocarbon removal rates were approximately 0.18 lb/day of TPH and 0.00020 lb/day of benzene. Thus, initially, mass removal in the vapor phase is not significant.

The initial soil gas profiles at the site displayed oxygen-deficient, carbon dioxide-rich, high total volatile hydrocarbon vapor conditions at depths greater than 16 ft, although some oxygen limitation was observed at shallower depths. These conditions indicate that natural biodegradation of residual petroleum hydrocarbons has occurred, but is limited by oxygen availability. Soil gas concentrations were measured during the bioslurper test at monitoring points adjacent to monitoring well H192S to determine if the vadose zone was being oxygenated via the bioslurper action. Soil gas concentrations were measured during the bioslurper test at monitoring points adjacent to monitoring well H192S to determine if the vadose zone was being oxygenated via the bioslurper action. Oxygen concentrations were influenced at all monitoring point, with oxygen concentrations in soil gas ranging from 16 to 20% by the end of the bioslurper pump test. These results correlate with the soil gas permeability test, where a radius of influence of 54 ft was measured. In situ biodegradation rates 0.94 of to 1.6 mg/kg-day were measured at three different locations. Based on the radius of influence of 54 ft and a hydrocarbon-impacted soil thickness of 28 ft, mass removal rates via biodegradation are on the order of 21 to 36 lbs of hydrocarbon per day. Thus, mass removal rates via biodegradation could be as significant as the vapor phase removal rates measured during the bioslurper test. These results indicate that bioventing is feasible at this site. Air injection bioventing is preferable over bioslurping and soil vapor extraction with respect to the elimination of hydrocarbon vapor emissions.

In summary, the on-site testing at Site SS-06, Wurtsmith AFB, included the direct testing of gravity-driven and vacuum-driven LNAPL free product recovery techniques, bioventing, physical sampling, and tests relevant to soil vapor extraction. Liquid phase recovery was only sustainable under vacuum-enhanced conditions, although recovery was low. The vacuum-enhanced mode is significant in that if liquid phase LNAPL recovery is not sustainable under high vacuum conditions, then it is unlikely that it will be sustainable under any conditions. The in situ respiration test and vadose zone radius of influence testing demonstrate that bioventing may be feasible at this site.

Bioslurping appears to be a suitable recovery technique for this site. The loss of LNAPL recovery at full vacuum may be avoided by installing wells that are more suited for bioslurping. The monitoring wells used were screened below the water table, and as such, probably limited the amount of free product which could be recovered.

DRAFT SITE-SPECIFIC TECHNICAL REPORT (A003)

for

FREE PRODUCT RECOVERY TESTING AT SITE SS-06, WURTSMITH AFB, MICHIGAN

24 March 1997

1.0 INTRODUCTION

This report describes activities performed and data collected during field tests at Wurtsmith Air Force Base (AFB), Michigan to compare vacuum-enhanced free-product recovery (bioslurping) to traditional free-product recovery technologies for removal of light, nonaqueous-phase liquid (LNAPL) from subsurface soils and aquifers. The field testing at Wurtsmith AFB is part of the Bioslurper Initiative, which is funded and managed by the U.S. Air Force Center for Environmental Excellence (AFCEE) Technology Transfer Division. The AFCEE Bioslurper Initiative is a multisite program designed to evaluate the efficacy of the bioslurping technology for (1) recovery of LNAPL from groundwater and the capillary fringe and (2) enhancing natural in situ degradation of petroleum contaminants in the vadose zone via bioventing.

1.1 Objectives

The main objective of the Bioslurper Initiative is to develop procedures for evaluating the potential for recovering free-phase LNAPL present at petroleum-contaminated sites. The overall study is designed to evaluate bioslurping and identify site parameters that are reliable predictors of bioslurping performance. To measure LNAPL recovery in a wide variety of in situ conditions, tests are being performed at many sites. The test at Wurtsmith AFB is one of more than 40 similar field tests to be conducted at various locations throughout the United States and its possessions. Aspects of the testing program that apply to all sites are described in the *Test Plan and Technical Protocol for Bioslurping* (Battelle, 1995). Test provisions specific to activities at Wurtsmith AFB are described in the Site-Specific Test Plan provided in Appendix A.

The intent of field testing is to collect data to support determination of the predictability of LNAPL recovery and to evaluate the applicability, cost, and performance of the bioslurping technology for removal of free product and remediation of the contaminated area. The on-site testing is structured to allow direct comparison of the LNAPL recovery achieved by bioslurping with the performance of more conventional LNAPL recovery technologies. The test method included an initial site characterization followed by LNAPL recovery testing. The three LNAPL recovery technologies tested at Wurtsmith AFB were skimmer pumping, bioslurping, and drawdown pumping. The specific test objectives, methods, and results for the Wurtsmith AFB test program are discussed in the following sections.

1.2 Testing Approach

Bioslurper pilot test activities were conducted at two monitoring wells at : (1) monitoring well H192S, and (2) monitoring well H196S. Site characterization activities were conducted to evaluate site variables that could affect LNAPL recovery efficiency and to determine the bioventing potential of the site. Testing included baildown testing to evaluate the mobility of LNAPL, soil sampling to determine physical/chemical site characteristics, soil gas permeability testing to determine the radius of influence, and in situ respiration testing to evaluate site microbial activity.

Following the site characterization activities, the pump tests were conducted. At monitoring well H192S, pilot tests for skimmer pumping, bioslurping, and drawdown pumping were conducted. The LNAPL recovery testing was conducted in the following sequence at monitoring well H192S: 48 hr in the skimmer configuration, 95 hr in the bioslurper configuration, an additional 23 hr in the skimmer configuration, and 25 hr in the drawdown configuration.

After the drawdown pump test at H192S, LNAPL recovery testing was conducted at monitoring well H196S for 14 hr in the bioslurper configuration.

Measurements of extracted soil gas composition, LNAPL thickness, and groundwater level were taken throughout the testing. The volume of LNAPL recovered and groundwater extracted were quantified over time.

2.0 SITE DESCRIPTION

The information presented in this section was obtained from *The United States Air Force Installation Restoration Program Second Draft RI/FS Work Plan: IRP Sites SS-06, ST-40 and SS-13* prepared for the U.S. Air Force Center for Environmental Excellence by ICF Technology Incorporated, June 1994.

Wurtsmith AFB is located in the northeastern portion of Michigan's lower peninsula in Iosco County and occupies an area of 5,221 acres. Wurtsmith AFB lies nearest to the city of Oscoda and is located less than 1 mile west of Lake Huron. The installation is bounded by Huron National Forest to the south, by Alpena State Forest to the west, and by man-made Van Etten Lake to the northeast. The proposed site for bioslurper activities is the POL Bulk Storage Area (Site SS-06), which is located in the east-central portion of Wurtsmith AFB (Figure 1).

Contamination at the site is associated with JP-4 jet fuel which was formerly stored in a 1.2-million-gallon aboveground storage tank identified as Tank 7,000. Contamination is likely to have resulted from leakage of this tank, which has since been drained and removed. There are no records of any major spills having occurred at the site.

Benzene, toluene, and organic compounds were first detected in the groundwater in 1979, and contamination as free floating product was found in 1983. As a result, an investigation was conducted by the U.S. Geological Survey (USGS) involving the installation of 8 shallow and 4 deep monitoring wells. A Benzene Pump and Treat Plant has been in operation since 1992 to remediate groundwater and remove free-floating product. The Benzene Plant consists of 4 purge wells and 2 air-stripper towers and operates in conjunction with a free-product recovery system.

The site geology consists of a layer of medium-grained sands from the surface to 70 ft below ground surface (bgs) interspersed with occasional silty-clay lenses. Thin gravel lenses are found rarely at the lower boundary of this unit. A silty-clay unit with an estimated thickness of 100 ft or greater underlies the unconsolidated glacial sediments. Units below this are unaffected by surface contamination.

The depth to groundwater at Wurtsmith AFB ranges from 3 to 25 ft bgs with water table elevations fluctuating approximately 1 to 3 ft annually. A large number of wells near the Benzene Pump and Treat Plant are screened at intervals below the oil/water interface and do not always account for water table fluctuations that occur as a result of seasonal variations. The aquifer corresponds with the sandy unit and extends to the silty-clay aquitard referred to above. A deeper aquifer exists; however, it seems to be isolated from the surficial hydrocarbon contamination. Groundwater in the vicinity of Site SS-06 flows northeast toward Van Etten Creek and Van Etten Lake; however, groundwater in the southern portion of the Base flows south to the Au Sable River. Extensive pumping involved in the operation of the Benzene Plant has resulted in a cone of depression in this area. The municipal water supply is separate from the groundwater system at the Base, and the Base itself is supplied with water from the city of Oscoda.

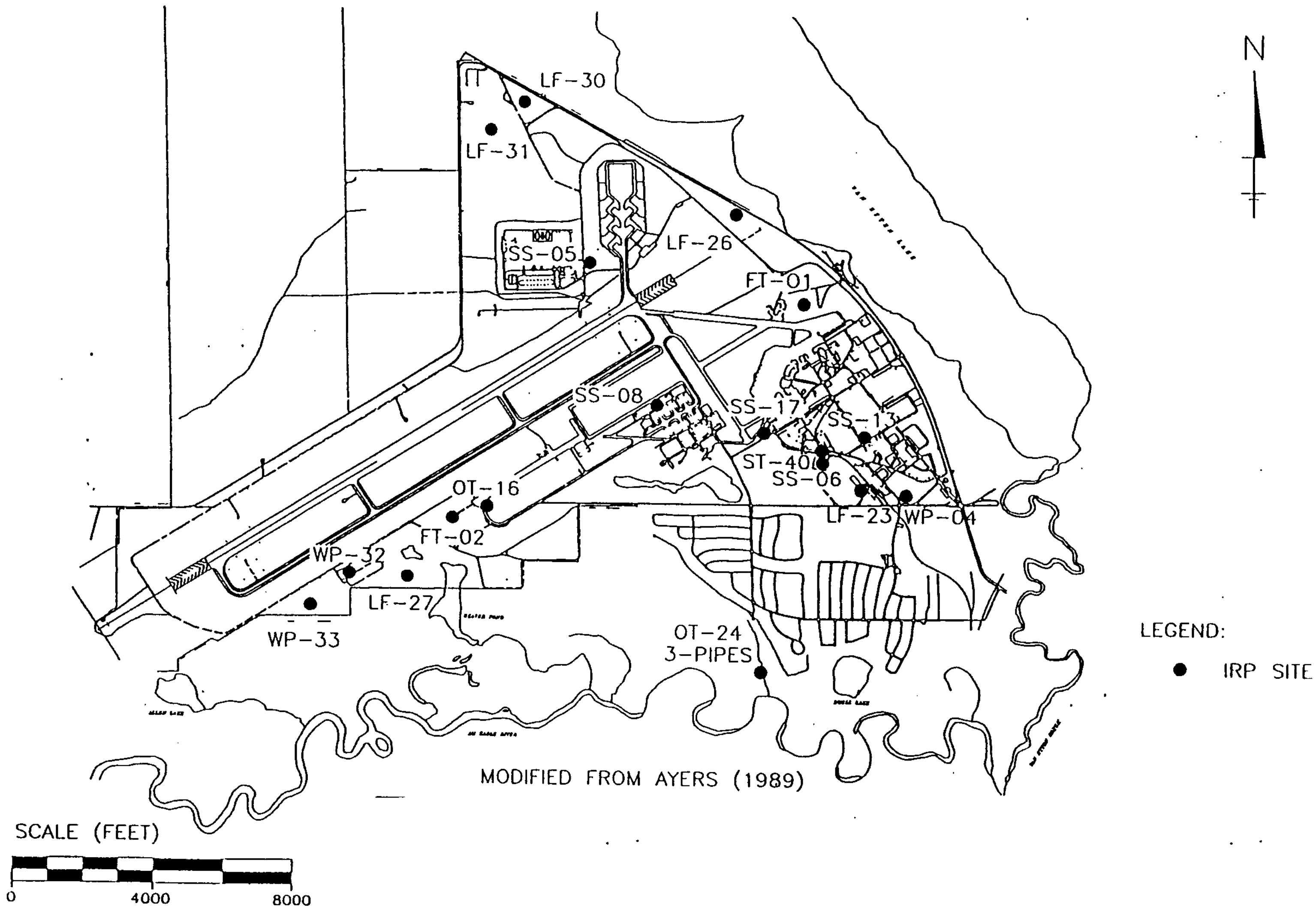

Figure 1. Site Map Showing Location of Site SS-06, Wurtsmith AFB, MI

Since the Benzene Plant has been in operation, only a slight decrease in benzene concentrations in groundwater has been seen. This could be accounted for by plant operation at less than optimal rates or a plume that is larger than originally anticipated. Measurements taken in July 1996 reveal that floating free product still exists in numerous wells at depths up to approximately 1 ft. The well locations are shown in Figure 2.

3.0 BIOSLURPER SHORT-TERM PILOT TEST METHODS

This section documents the initial conditions at the test site and describes the test equipment and methods used for the short-term pilot test at Wurtsmith AFB.

3.1 Initial LNAPL/Groundwater Measurements and Baildown Testing

Monitoring wells H192S and H196S were evaluated for use in the bioslurper pilot testing. Initial depths to LNAPL and to groundwater were measured using an oil/water interface probe (ORS Model #1068013). LNAPL was removed from the well with a Teflon™ bailer until the LNAPL thickness could no longer be reduced. The rate of increase in the thickness of the floating LNAPL layer was monitored using the oil/water interface probe for approximately 19 hr at monitoring well H196S, and for approximately 20 hr at monitoring well H192S.

An LNAPL sample was collected from monitoring well H192S for analysis of BTEX and for boiling point fractionation and was labeled WUR-FP-1. The sample was sent to Alpha Analytical, Inc., in Sparks, Nevada for analysis.

3.2 Well Construction Details

Short-term bioslurper pump tests were conducted at existing monitoring well H192S and at monitoring well H196S. Monitoring wells H192S and H196S are constructed of 4-inch-diameter, schedule 40 polyvinyl chloride (PVC). Total well depth is 40.6 ft with a screen length of 4.0 ft. A schematic diagram illustrating general well construction details for monitoring wells H192S and H196S is provided in Figure 3.

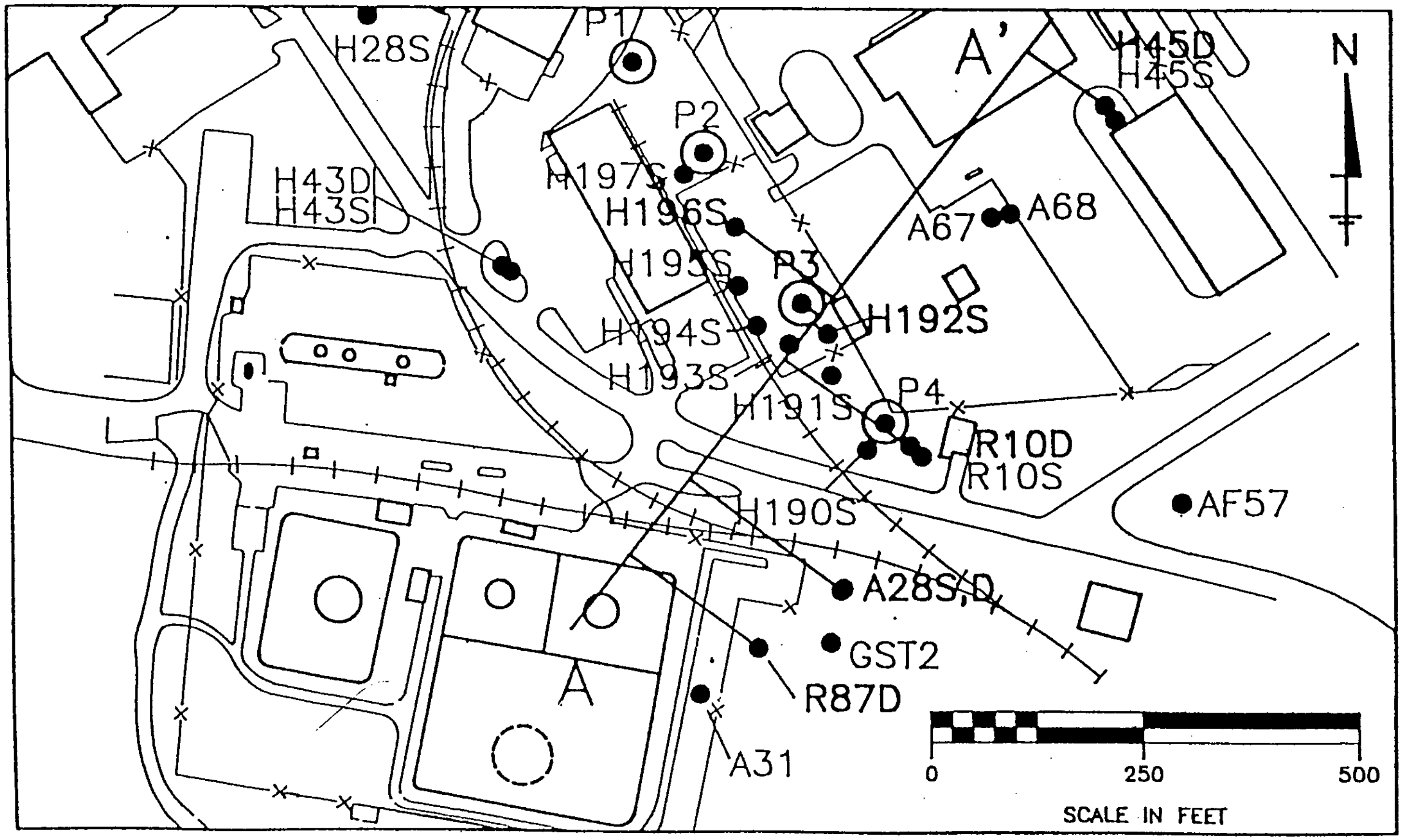

Figure 2. Schematic Diagram Showing Monitoring Well Locations at Site SS-06, Wurtsmith AFB, MI

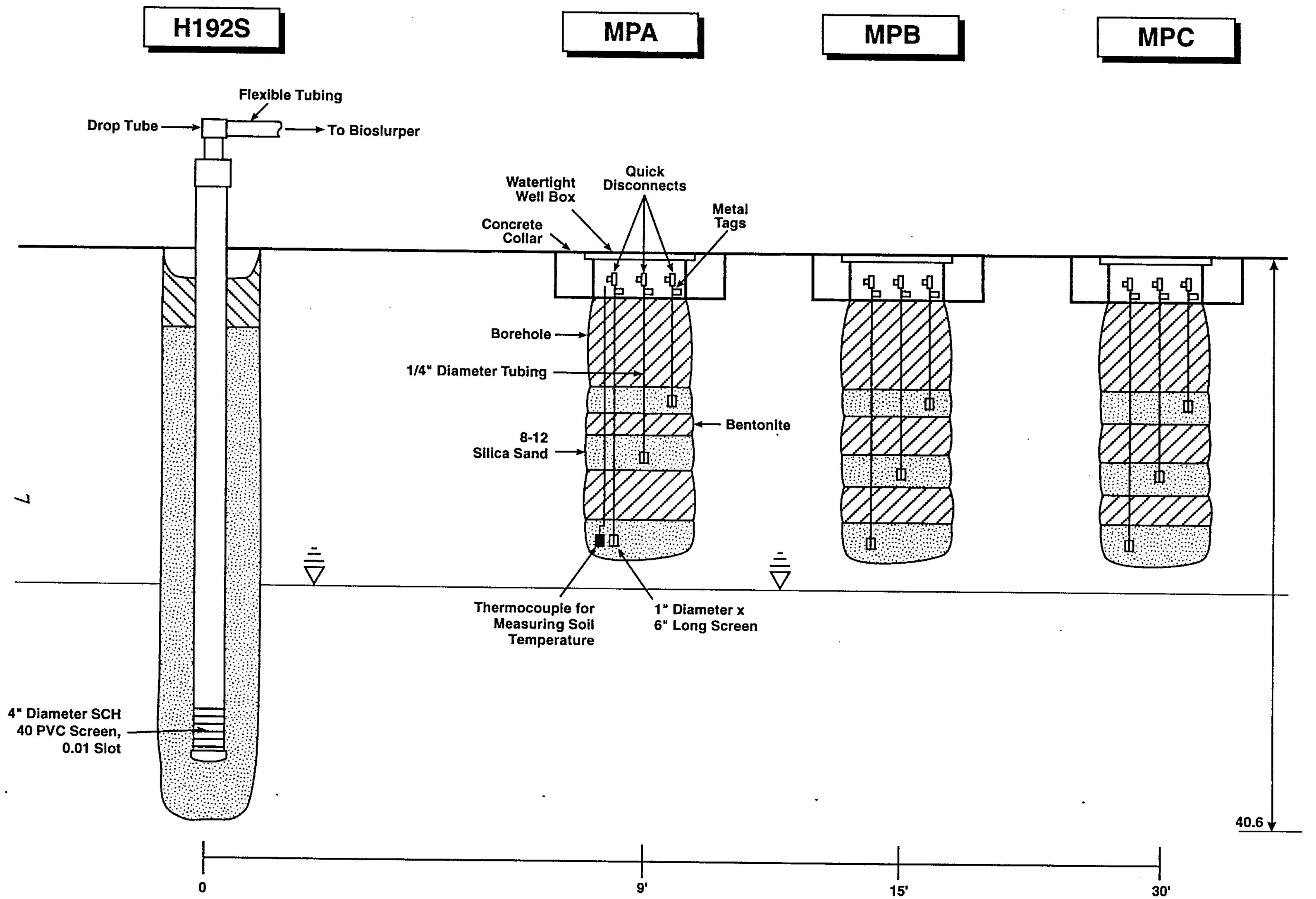

Figure 3. Construction Details of Monitoring Well H192S and Soil Gas Monitoring Points at Wurtsmith AFB, MI

3.3 Soil Gas Monitoring Point Installation

Three monitoring points were installed and labeled WU-MPA, WU-MPB, and WU-MPC. The locations and constructions details of the monitoring points are illustrated in Figure 4.

The monitoring points consisted of ¼-inch tubing, with 1-inch-diameter, 6-inch-long screened areas. The screened lengths were positioned at depths of 11, 15, and 21 ft bgl at monitoring point WU-MPA and at depths of 11, 16, and 21 ft bgl at monitoring points WU-MPB and WU-MPC. The annular space corresponding to the screened length was filled with silica sand. The interval from the top of the screened length to the bottom of the next screened length, as well as the interval from the ground surface to the top of the first screened length, was filled with bentonite clay chips. After placement, the bentonite clay was hydrated with water to expand the chips and provide a seal.

Type K thermocouples were installed with monitoring point WU-MPA at depths of 11 and 21 ft bgl.

After installation of the monitoring points, initial soil gas measurements were taken with a GasTech portable O_2/CO_2 meter and a GasTech TraceTechtor portable hydrocarbon meter. Oxygen limitation was observed at most monitoring points, with oxygen concentrations below 5% at depths deeper than 16 ft. TPH concentrations were high at the deeper depths, ranging from 98,000 ppmv to greater than 100,000 ppmv (Table 1).

3.4 Soil Sampling and Analysis

Two soil samples were collected during the installation of monitoring point WU-MPA and were labeled WUR-SS-1 and WUR-SS-2. Sample WUR-SS-1 was collected from 19.75 to 20.25 ft bgl and sample WUR-SS-2 was collected from 21.5 to 22 ft bgl using a split spoon sampler with brass sleeves. The samples were placed in an insulated cooler, chain-of-custody records and shipping papers were completed, and the samples were sent to Alpha Analytical, Inc., in Sparks, Nevada. Samples were analyzed for BTEX, bulk density, moisture content, particle size, porosity, and TPH. The laboratory analytical report is provided in Appendix B.

Table 1. Initial Soil-Gas Compositions at Site SS-06, Wurtsmith AFB, MI

Monitoring Point	Depth (ft)	Oxygen (%)	Carbon Dioxide (%)	TPH (ppmv)
WU-MPA	11.0	10.5	6.6	200
	15.0	6.5	9.5	2,400
	21.0	0	15.9	>100,000
WU-MPB	11.0	10.9	6.0	880
	16.0	22	11.5	11,000
	21.0	0	15.9	98,000
WU-MPC	11.0	16.9	4.2	1,600
	16.0	3.8	9.0	860
	21.0	0.5	15.0	>100,000

3.5 LNAPL Recovery Testing

3.5.1 System Setup

The bioslurping pilot test system is a trailer-mounted mobile unit. The vacuum pump (Atlantic Fluidics Model A100, 7.5-hp liquid ring pump), filter box, oil/water separator, and required support equipment were carried to the test location on a trailer. The trailer was located near the monitoring well, the well cap was removed, a well seal was placed on the top of the well, and the slurper tube was lowered into the well. The slurper tube was attached to the vacuum pump. Different configurations of the well seal and the placement depth of the slurper tube allow for simulation of skimmer pumping, operation in the bioslurping configuration, or simulation of drawdown pumping. Extracted soil gas was reinjected into the vadose zone through monitoring wells H190S, H191S, H193S, and H194S. Extracted groundwater was treated by passing the recovered fluid through the filter box, the oil/water separators, and a settling tank. The groundwater was then discharged into the base's treatment plant.

A brief system startup test was performed prior to LNAPL recovery testing to ensure that all system components were working properly. The system checklist is provided in Appendix C. All site data and field testing information were recorded in a field notebook and then transcribed onto pilot test data sheets provided in Appendix D.

3.5.2 Skimmer Pump Test

Prior to test initiation, depths to LNAPL and groundwater were measured. A peristaltic pump was used to conduct the skimmer pump test with the wellhead open to the atmosphere. The tubing was held in position at 27.5 ft bgl. The peristaltic pump was started 11:30 am, 30 July 1996, to begin the skimmer pump test. The test was operated continuously for 48 hr. The LNAPL and groundwater extraction rates were monitored throughout the test, as were all other relevant data for the skimmer pump test. Test data sheets are provided in Appendix D.

3.5.3 Bioslurper Pump Test

Two bioslurper pump tests were conducted: one at monitoring well H192S and one at monitoring well H196S. Details of the tests are described in the following sections.

3.5.3.1 Monitoring Well H192S

Upon completion of the skimmer pump test, preparations were made to begin the bioslurper pump test. The LNAPL and groundwater depth were measured prior to any recovery testing. The slurper tube was set at the LNAPL/groundwater interface at a depth of 27.5 ft bgl. The sanitary well seal was positioned inside the well, sealing the wellhead and allowing the pump to establish a vacuum in the well (Figure 4). A pressure gauge was installed at the wellhead to measure the vacuum inside the extraction well. The liquid ring pump was started at 7 pm, 1 August 1996, to begin the bioslurper pump test. The test was initiated approximately 7.5 hr after the skimmer pump test and was operated for 95 hr. The pump test was initiated at approximately one-half vacuum (15″Hg, dropping to 11″Hg), and after 63 hr, the pump vacuum was raised to full vacuum (18″Hg). Vapor flowrates ranged from 30 to 33 scfm during the one-half vacuum test and from 15 to 18 scfm during the full vacuum test. Well vacuums ranged from 2.3 to 4.8 ″H_2O during the one-half vacuum test

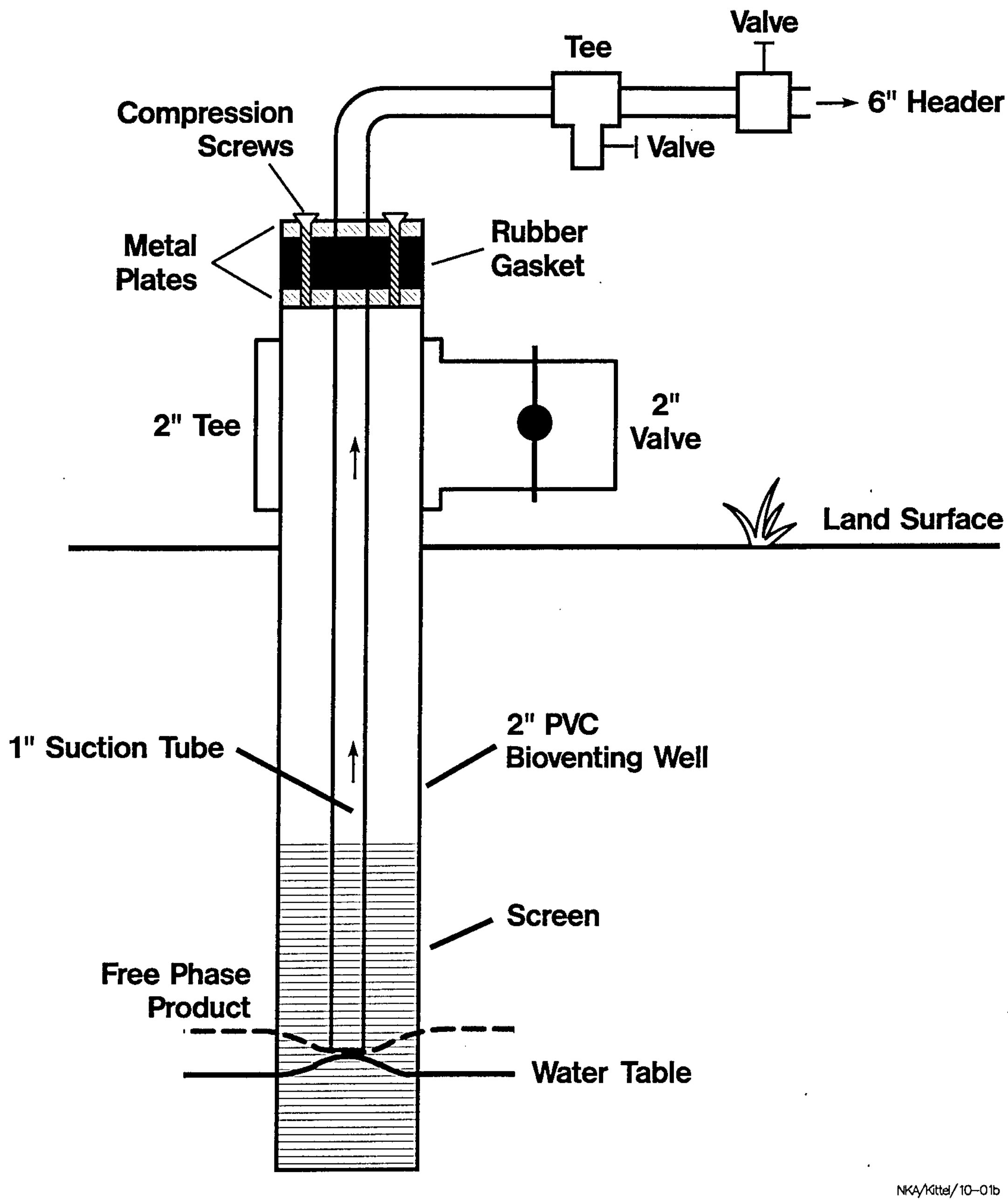

Figure 4. Slurper Tube Placement for the Bioslurper Pump Test

and from 5.0 to 5.5 "H_2O during the full vacuum test. The LNAPL and groundwater extraction rates were monitored throughout the test, as were all other relevant data for the bioslurper pump test. The data sheets are provided in Appendix D.

3.5.3.2 Monitoring Well H196S

The bioslurper system was configured as described in Section 3.5.3.1. The slurper tube was set at the LNAPL/groundwater interface at a depth of 28.19 ft bgl. The liquid ring pump was started at 8:10 pm, 7 August 1996, to begin the bioslurper pump test. The test was initiated approximately 2 hr after termination of the drawdown pump test at monitoring well H192S. The pump vacuum was approximately 18″Hg, the well vacuum was approximately 2.5″H_2O, and the vapor flowrate was approximately 15 scfm. The LNAPL and groundwater extraction rates were monitored throughout the test, as were all other relevant data for the bioslurper pump test. Test data sheets are provided in Appendix D.

3.5.4 Second Skimmer Pump Test

Upon completion of the bioslurper pump test at monitoring well H192S, preparations were made to begin the second skimmer pump test. Prior to test initiation, depths to LNAPL and groundwater were measured. The bioslurper system was used to conducted this skimmer pump test. The slurper tube was set at a depth of 27′2″ bgl. The drop tube was held in position by the well seal, and was positioned to leave the wellhead vented to the atmosphere (Figure 5). The liquid ring pump and oil/water separator were primed with known amounts of groundwater to ensure that any LNAPL or groundwater entering the system could be quantified. The flow totalizers for the LNAPL and aqueous effluent were zeroed, and the liquid ring pump was started at 6:30 pm, 5 August 1996, to begin the second skimmer pump test. The test was initiated approximately 0.5 hour after the bioslurper pump test and was operated continuously for 22.5 hours. The pump vacuum was approximately 9″Hg and the vapor flowrate was approximately 35 scfm. The LNAPL and groundwater extraction rates were monitored throughout the test, as were all other relevant data for the bioslurper pump test. Test data sheets are provided in Appendix D.

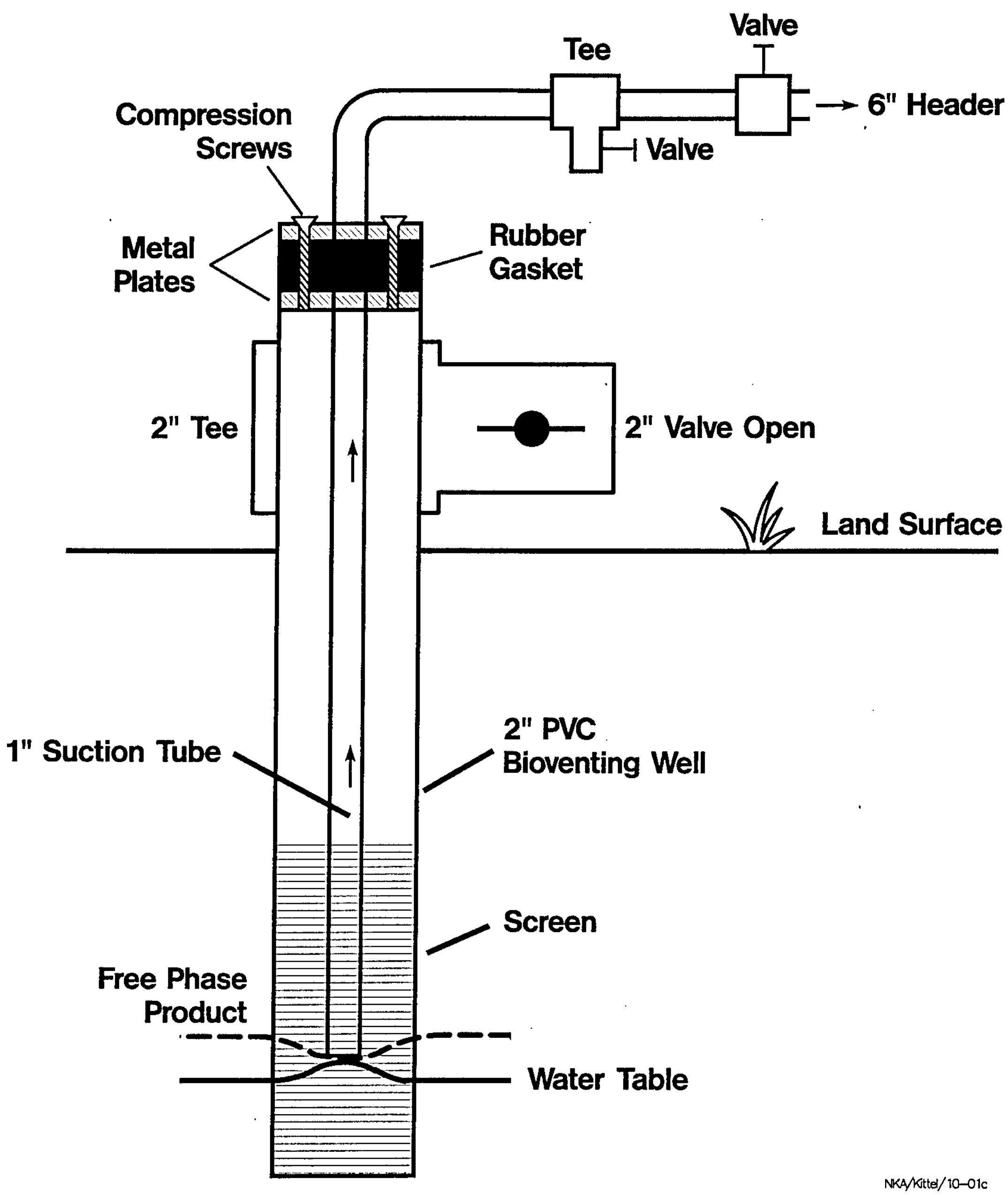

Figure 5. Slurper Tube Placement and Valve Position for the Skimmer Pump Test

3.5.5 Drawdown Pump Test

Upon completion of the second skimmer pump test, preparations were made to begin the drawdown pump test. Drawdown testing was conducted to determine if a cone of groundwater depression would enhance LNAPL recovery. The slurper tube was positioned 5 inches below the LNAPL/water interface measured prior to any recovery pump testing (Figure 6). The liquid ring pump was started at 5:30 pm, 6 August 1996, to begin the drawdown pump test. The test was initiated approximately 0.5 hr after the second skimmer pump test was completed and was operated continuously for 24.5 hr. The pump vacuum was approximately 18"Hg and the vapor flowrate was approximately 12 scfm. The LNAPL and groundwater extraction rates were monitored throughout the test, as were all other relevant data for the drawdown pump test. Test data sheets are provided in Appendix D.

3.5.6 Off-Gas Sampling and Analysis

Three soil gas samples were collected during the pump tests at monitoring well H192S. Samples WUR-REINJECT-1 and WUR-REINJECT-2 were collected during the bioslurper pump test at monitoring well H192S after 21 and 24.25 hr of operation, respectively. Sample WUR-REINJECT-3 was collected during the second skimmer pump test following approximately 4 hr of operation. The samples were collected in Summa™ canisters and sent under chain of custody to Air Toxics, Ltd., in Folsom, California, for analyses of BTEX and TPH, using EPA Method TO-3.

3.5.7 Groundwater Sampling and Analysis

Five groundwater samples were collected during the pump tests at monitoring well H192S and were labeled WUR-H_2O-1, WUR-H_2O-2, WUR-H_2O-3, WUR-H_2O-4, and WUR-H_2O-5. Each sample was collected from the settling tank. Samples WUR-H_2O-1, WUR-H_2O-2, and WUR-H_2O-3 were collected during the bioslurper pump test after approximately 17, 73, and 73 hr of operation, respectively. Samples WUR-H_2O-4 and WUR-H_2O-5 were collected during the second skimmer pump test after approximately 17 hr of operation. Samples were collected in 40-mL septa vials containing hydrochloric acid (HC1) preservative. Samples were checked to ensure no headspace was

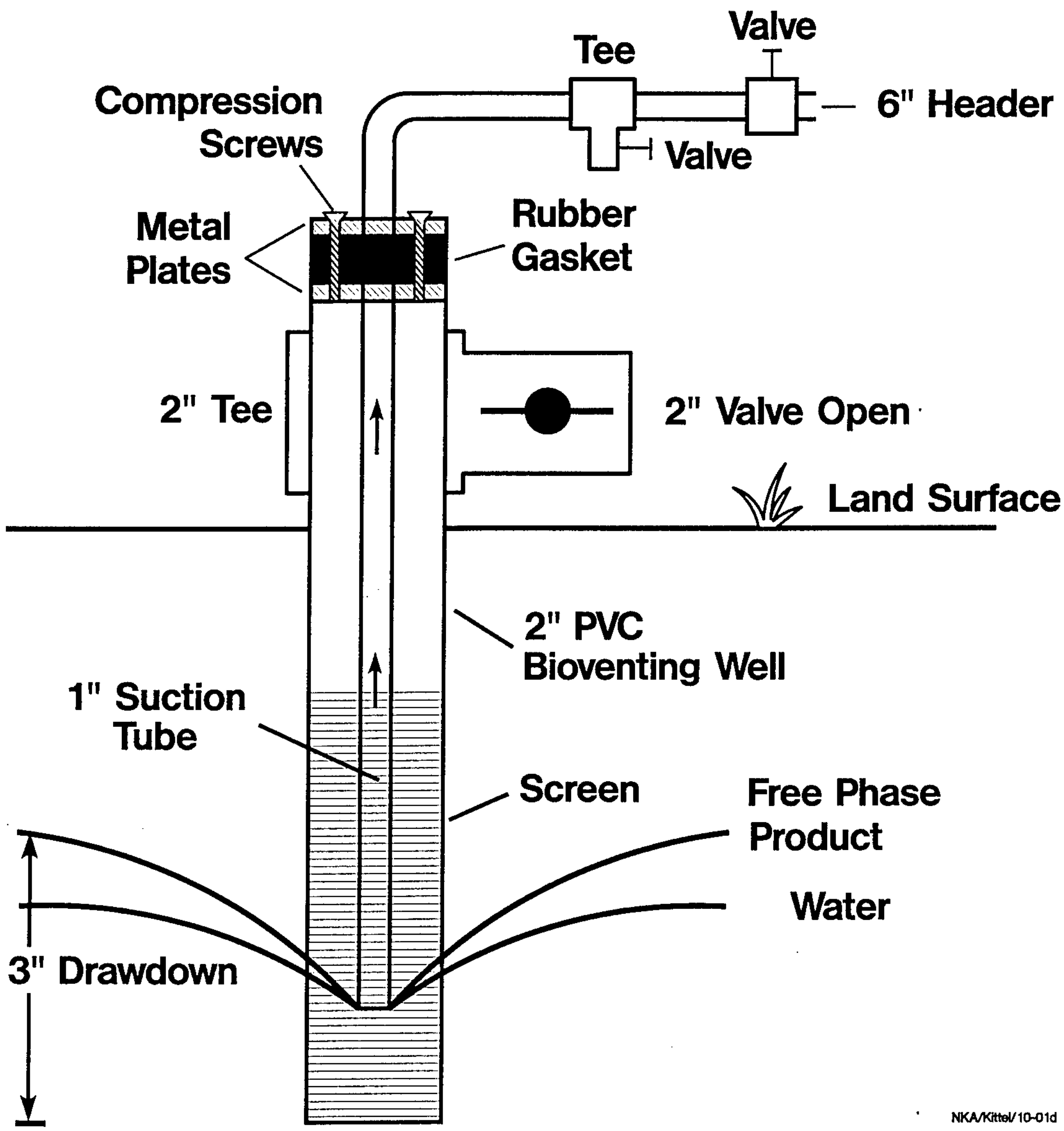

Figure 6. Slurper Tube Placement for Drawdown Pump Test

present and were then shipped on ice and sent under chain of custody to Alpha Analytical, Inc., in Sparks, Nevada for analyses of BTEX and TPH (purgeable).

3.6 Bioventing Analyses

3.6.1 Soil Gas Permeability Testing

The soil gas permeability test data were collected during the bioslurper pump test at monitoring well H192S. Before a vacuum was established in the extraction well, the initial soil gas pressures at the three installed monitoring points were recorded. The start of the bioslurper pump test created a steep pressure drop in the extraction well which was the starting point for the soil gas permeability testing. Soil gas pressures were measured at each of the three monitoring points at all depths to track the rate of outward propagation of the pressure drop in the extraction well. Soil gas pressure data were collected frequently during the first 20 minutes of the test. The soil gas pressures were recorded throughout the bioslurper pump test to determine the bioventing radius of influence. Test data are provided in Appendix E.

3.6.2 In Situ Respiration Testing

Air containing approximately 2% helium was injected into three monitoring points for approximately 25 hr beginning on 6 August 1996. The setup for the in situ respiration test is described in the *Test Plan and Technical Protocol a Field Treatability Test for Bioventing* (Hinchee et al., 1992). A ½-hp diaphragm pump was used for air and helium injection. Air and helium were injected through monitoring points WU-MPA-21.0′, WU-MPB-21.0′, and WU-MPC-21.0′. After the air/helium injection was terminated, soil gas concentrations of oxygen, carbon dioxide, TPH, and helium were monitored periodically. The in situ respiration test was terminated on 11 August 1996. Oxygen utilization and biodegradation rates were calculated as described in Hinchee et al. (1992). Raw data for these tests are presented in Appendix F.

Helium concentrations were measured during the in situ respiration test to quantify helium leakage to or from the surface around the monitoring points. Helium loss over time is attributable to either diffusion through the soil or leakage. A rapid drop in helium concentration usually indicates leakage. A gradual loss of helium along with a first-order curve generally indicates diffusion. As a rough estimate, the diffusion of gas molecules is inversely proportional to the square root of the molecular weight of the gas. Based on molecular weights of 4 for helium and 32 for oxygen, helium diffuses approximately 2.8 times faster than oxygen, or the diffusion of oxygen is 0.35 times the rate of helium diffusion. As a general rule, we have found that if helium concentrations at test completion are at least 50 to 60% of the initial levels, measured oxygen uptake rates are representative. Greater helium loss indicates a problem, and oxygen utilization rates are not considered representative.

3.6.3 Surface Emissions Testing

One of the concerns over the reinjection of off-gas is the possibility of transferring soil contaminants to the atmosphere through air-stripping of organics. To determine if there is any significant release of volatile organic compounds (VOCs) to the atmosphere during bioventing, surface emissions testing was performed.

A dynamic surface emissions sampling methodology was used at Wurtsmith AFB. This method involved enclosing an area of soil under an inert box designed to allow the purging of the enclosure with high-purity air (Dupont, 1987). The purging removed ambient air from the region above the soil and allowed an equilibrium to be established between the hydrocarbons emitted from the soil and the organic-free air. The air stream was then sampled by drawing a known volume of the hydrocarbon/pure air mixture through a tube packed with sorbent materials. The sorbents retained any organics associated with surface emissions. The sample tube was thermally desorbed, and the organics were resolved and quantified by GC. These measured concentrations were then used to calculate the emission rates for the hydrocarbons from the soil to the atmosphere.

A schematic diagram of the surface emissions sampling system is shown in Figure 7. The system consisted of a square Teflon™ box that covered a surface area of 0.45 m^2. The box was fitted with inlet and outlet ports for the entry and exit of high-purity air. Inside the box was a manifold that delivered the air supply uniformly across the soil surface. The same type of manifold was fitted to the exit port of the box. This configuration delivered an even flow of air across the entire soil surface under the box so that a representative sample was being generated.

The air exiting the Teflon™ box was directed to a sampling box. This box contained the sorbent tube and an SKC personal monitoring pump, Model #224-PCXR7. Also attached to the box was a purge line that accommodated the excess flow from the Teflon™ box that was not drawn into

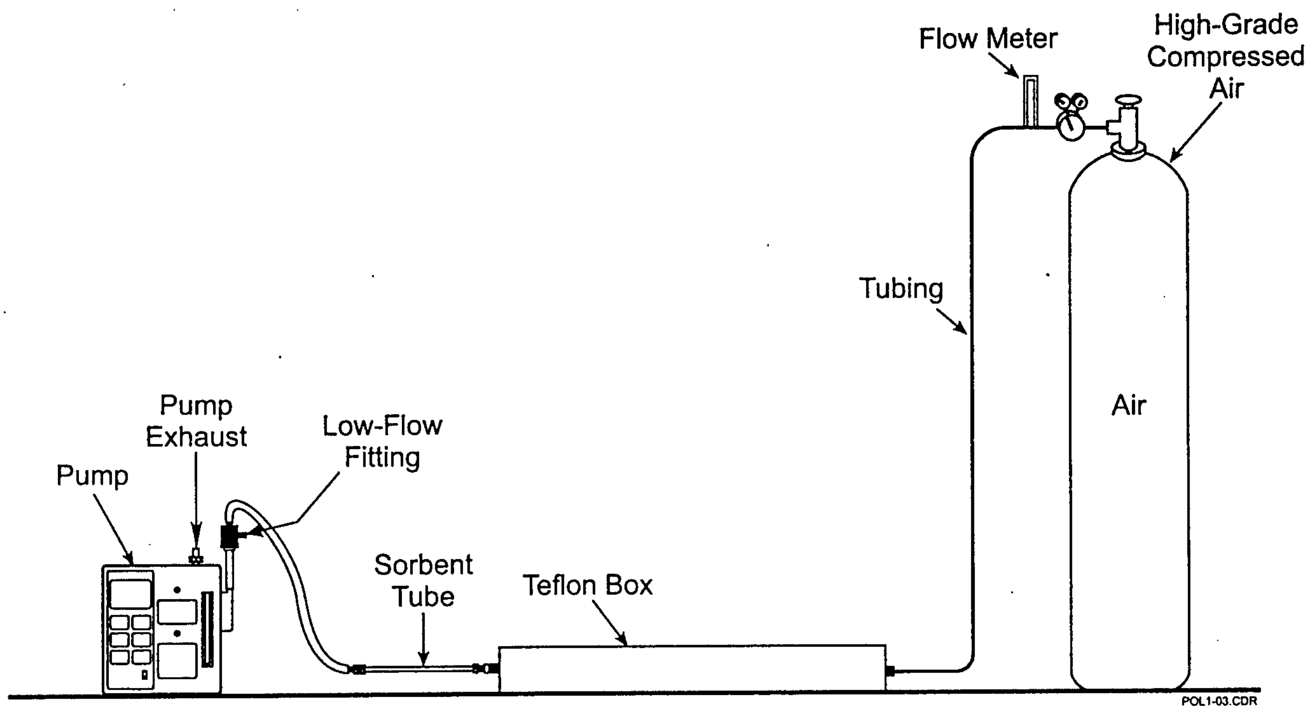

Figure 7. Schematic Diagram of the Surface Emissions Sampling System

the sorbent tube. A Magnehelic™ gauge indicated whether zero pressure was being maintained throughout the entire system.

In all cases, a totally inert system was employed. Teflon™ tubing and stainless steel fittings assured that there was no contribution to or removal of organics from the air stream. The pump was located on the back side of the sorbent trap so that it was not in a position to contaminate the sample flow.

Two surface emission samples were collected from a location approximately centered within the four wells used for reinjection of off-gases. Air was pulled through the sorbent tube at a flowrate of approximately 50 mL/minute over a 6-minute interval, resulting in a 300-mL sample volume.

4.0 RESULTS

This section documents the results of the site characterization, the comparative LNAPL recovery pump test, and other supporting tests conducted at Wurtsmith.

4.1 Baildown Test Results

Results from the baildown tests are presented in Table 2. Baildown recovery tests provide a qualitative indication of the presence of mobile, free-phase LNAPL and recovery potential. Overall, the baildown recovery tests indicated a moderate rate of LNAPL recovery into the wells. At monitoring well H192S, LNAPL recovered to approximate initial levels by the end of the 28 hr baildown test. At monitoring well H196S, LNAPL recovered to a level approximately ⅓ of the initial LNAPL thickness. Based on these results, pilot testing was initiated on monitoring well H192S.

4.2 Soil Sample Analyses

Table 3 shows the TPH and BTEX concentrations measured in soil samples collected from Site SS-06. TPH and BTEX concentrations were below detection limits in both samples, except for a small amount of xylene (0.036 mg/k) detected in sample WUR-SS-2. The results of the physical characterization and inorganic analysis of the soil are presented in Table 4. Soils were very permeable, with soils consisting primarily of sand.

Table 2. Results of Baildown Testing in Monitoring Well H192S, Wurtsmith AFB, MI

Monitoring Well	Sample Collection Time	Depth to Groundwater (ft)	Depth to LNAPL (ft)	LNAPL Thickness (ft)
H192S	Initial Reading 7/29/96-1200	28.03	27.17	0.86
	7/29/96-1210	27.48	27.23	0.25
	7/29/96-1235	27.54	27.22	0.32
	7/29/96-1424	27.76	27.17	0.59
	7/29/96-1630	27.84	27.14	0.70
	7/29/96-1840	27.87	27.14	0.73
	7/29/96-1953	27.89	27.13	0.76
	7/30/96-753	27.82	27.09	0.73
H196S	Initial Reading 7/29/96-1215	28.79	28.02	0.77
	7/29/96-1225	28.33	28.12	0.21
	7/29/96-1250	28.34	28.12	0.22
	7/29/96-1427	28.35	28.12	0.23
	7/29/96-1645	28.35	28.11	0.24
	7/29/96-1850	28.34	28.11	0.23
	7/30/96-740	28.36	28.07	0.29

Table 3. TPH and BTEX Concentrations in Soil Samples from Site SS-06, Wurtsmith AFB, MI

Parameter	Concentration (mg/kg)	
	WUR-SS-1	WUR-SS-2
TPH (Purgeable)	<10	<10
Benzene	<0.020	<0.020
Toluene	<0.020	<0.020
Ethylbenzene	<0.020	<0.020
Xylenes	<0.020	0.036

Table 4. Physical Characterization of Soils from Site SS-06, Wurtsmith AFB, MI

Parameter		Sample	
		WUR-SS-1	WUR-SS-2
Moisture Content (%)		5.07	4.06
Density (g/cm^3)		1.21	1.20
Porosity (%)		54.3	54.8
Particle Size	Sand	97.1	97.1
	Silt	0.3	0.3
	Clay	2.6	2.6

4.3 LNAPL Pump Test Results

4.3.1 Initial Skimmer Pump Test Results

A small quantity of LNAPL was recovered during this test during 48 hr of continuous extraction (Table 5). The initial LNAPL recovery rate was 1.5 gallons/day, which dropped to 1.25 gallons/day be the second day of testing. A total of approximately 300 gallons of groundwater was produced with an average production rate of 150 gallons/day. Results of LNAPL recovery versus time are shown in Figure 8.

4.3.2 Bioslurper Pump Test Results

4.3.2.1 Monitoring Well H192S

LNAPL recovery was possible during the bioslurper pump test although recovery rates were low (Figure 7). Bioslurper testing was conducted for four days resulting in relatively low recovery on the first day (2.3 gallons/day), followed by steadily dropping recovery rates. The LNAPL recovery rate dropped to 0.40 gallons/day by hour 63. At this point, the pump vacuum was increased to full vacuum, and a slight increase in LNAPL recover was observed (0.71 gallons/da); however, recovery dropped to 0 by day 4. The loss of LNAPL recovery is likely due to the drop in the vapor extraction rate. A total of 4.5 gallons of LNAPL and 14,980 gallons of groundwater was extracted, with daily average recovery rates of 1.1 gallons/day for LNAPL and 3,700 gallons/day for groundwater (Table 5). The LNAPL recovery rate versus time is shown in Figure 9.

Soil gas concentrations were measured during the bioslurper test at monitoring points adjacent to monitoring well H192S to determine if the vadose zone was being oxygenated via the bioslurper action. Oxygen concentrations were influenced at all monitoring point, with oxygen concentrations in soil gas ranging from 16 to 20% by the end of the bioslurper pump test (Table 6). These results correlate with the soil gas permeability test, where a radius of influence of 54 ft was measured.

Table 5. Pump Test Results at Monitoring Well H192S, Site SS-06, Wurtsmith, MI

Time (days)	Recovery Rate (gal/day)							
	Skimmer Pump Test		Bioslurper Pump Test		Second Skimmer Pump Test		Drawdown Pump Test	
	LNAPL	Groundwater	LNAPL	Groundwater	LNAPL	Groundwater	LNAPL	Groundwater
1	1.5	149	2.5	5,200	0	830	0	1,900
2	1.25	150	1.5	3,020	NA	NA	NA	NA
3[1]	NA	NA	0.40	3,400	NA	NA	NA	NA
3[2]	NA	NA	0.71	3,000	NA	NA	NA	NA
4	NA	NA	0	3,400	NA	NA	NA	NA
Average (gal/day)	1.375	150	1.10	3,700	0	830	0	1,900
Total Recovery (gal)	2.75	300	4.5	14,980	0	778	0	2,100

NA Not applicable.
[1] Represents recovery rate from 48 to 63 hr after pump test initiation, when pump was operating at approximately one-half maximum vacuum.
[2] Represents recovery rate from 63 to 71.5 hr after pump test initiation, when pump was operating at full vacuum.

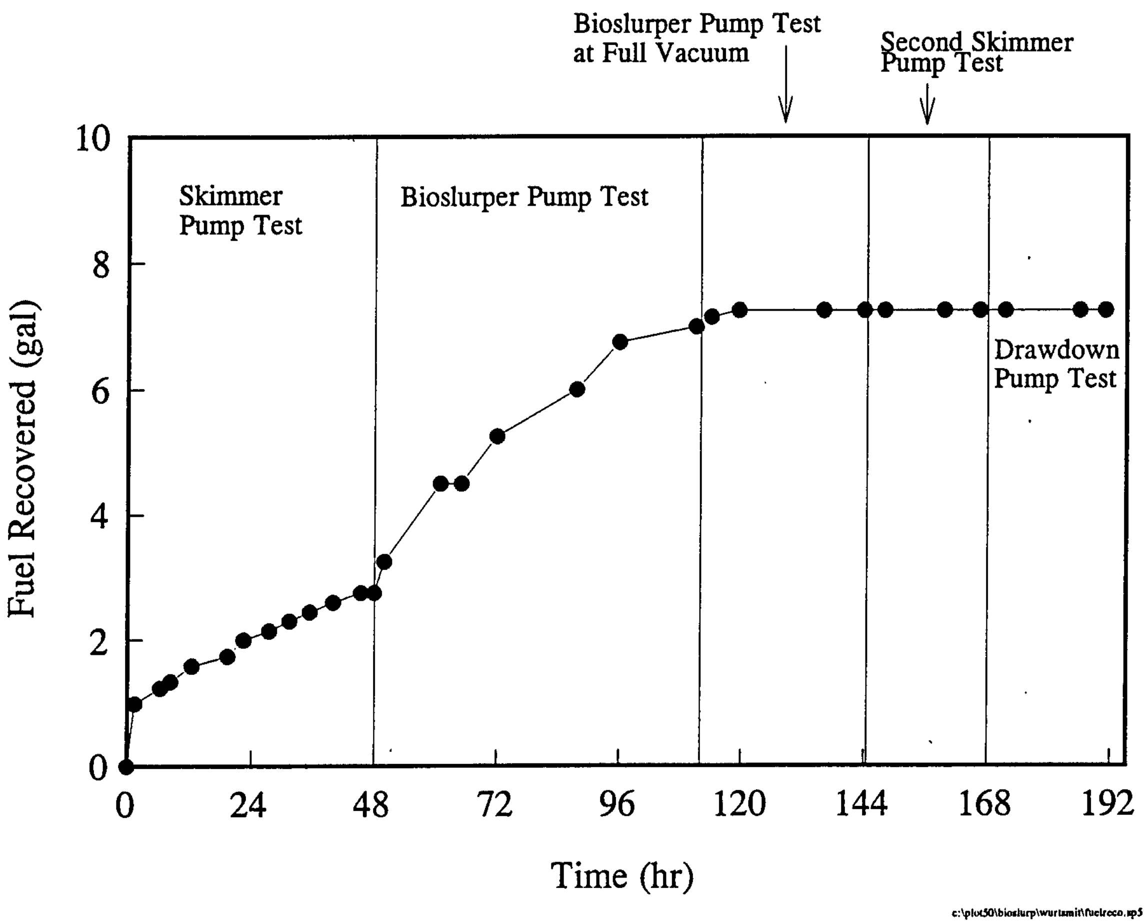

Figure 8. Fuel Recovery Versus Time During Each Pump Test in Monitoring Well H192S

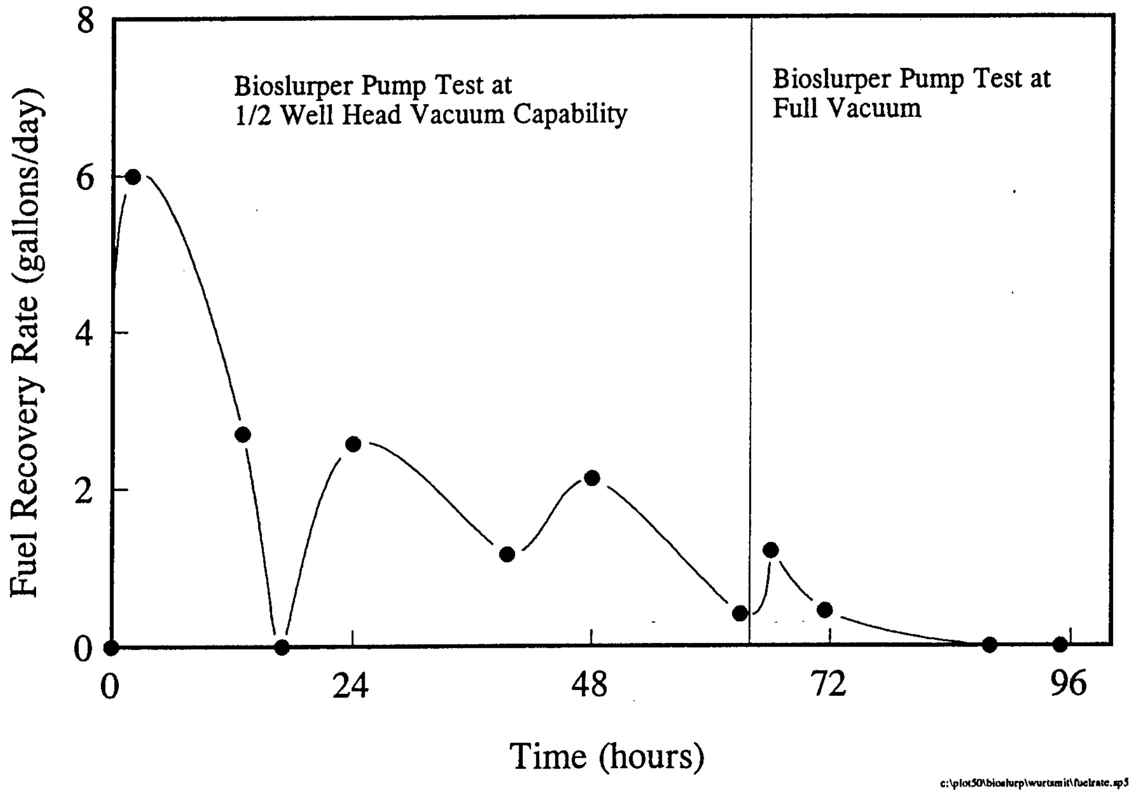

Figure 9. **LNAPL Recovery Rate Versus Time During the Bioslurper Pump Test at Monitoring Well H192S**

Table 6. Oxygen Concentrations During the Bioslurper Pump Test at H192S, Site SS-06, Wurtsmith AFB, MI

Monitoring Point	Depth (ft)	Oxygen Concentrations (%) Versus Time (hours)									
		0	3	17.3	27.0	39.8	48	64.7	71.8	88.1	95.3
WU-MPA	11.0	10.5	9.9	10.9	10.0	16.0	17.0	19.0	18.0	19.1	18.0
	15.0	6.5	0	5.2	6.0	11.0	17.0	15.0	15.1	16.0	17.0
	21.0	0	0	0	0.8	5.5	12.1	16.9	18.0	18.2	18.3
WU-MPB	11.0	10.9	7.5	8.0	7.0	15.5	18.0	18.0	17.5	14.9	16.5
	16.0	2.2	0	2.8	1.3	9.5	9.9	12.0	12.1	13.9	16.0
	21.0	0	0	0	1.3	5.5	8.0	13.0	14.1	18.5	17.2
WU-MPC	11.0	16.9	11.1	10.0	17.0	18.0	18.9	16.5	17.5	17.1	18.0
	16.0	3.8	2.9	2.5	0	11.75	15.5	20.0	20.5	20.0	20.0
	21.0	0.5	0	0.2	1.2	3.0	15.0	18.1	17.9	18.5	19

4.3.2.2 Monitoring Well H196S

In an effort to determine if the results at monitoring well H192S were representative of site conditions, bioslurper testing was conducted at monitoring well H196S. Minimal free-phase LNAPL was recovered during the half day of bioslurper pumping (2.2 gallons/day) (Table 7). The well head vacuum on monitoring well H196S (2.5"H_2O) and groundwater production rate (5,000 gallons/day) were similar to those observed at monitoring well H192S. Results at monitoring wells H192S and H196S appear to be representative of the site and indicate that gravity-driven liquid recovery techniques are not feasible and that vacuum-enhanced recovery is minimal.

4.3.3 Second Skimmer Pump Test

No LNAPL was recovered during approximately 24 hours of a second skimmer pump testing. Approximately 830 gallons of groundwater were recovered during the second skimmer pump test, with a daily average recovery rate of 830 gallons/day (Table 5). These results demonstrate that operation of the bioslurper system in the skimmer mode was not an effective means of free-product recovery.

4.3.4 Drawdown Pump Test

Drawdown pump testing was conducted to determine if a cone of groundwater depression would enhance LNAPL recovery. The water table was depressed 5 inches below the static water table in monitoring well H192S. No measurable LNAPL free product was recovered in this mode during one day of continuous extraction (Table 5). Groundwater recovery rates were on the order of 1,900 gallons/day. These results demonstrate that the vacuum gradient maintained during the bioslurper test resulted in higher fluid recovery rates than the 5 inch-groundwater drawdown test.

4.3.5 Extracted Groundwater, LNAPL, and Off-Gas Analyses

Results of groundwater analyses are shown in Table 8. Contaminant concentrations were similar between the samples, with average TPH and total BTEX concentrations of 4.5 mg/L and 0.21 mg/L, respectively. The on-site water treatment equipment, consisting of a filter tank, oil/water

Table 7. Pump Test Results at Monitoring Well H196S, Site SS-06, Wurtsmith AFB, MI

Time (days)	Recovery Rate (gal/day)	
	LNAPL	Groundwater
1	2.2	5,000
Total Recovery (gal)	1.25	2,810

Table 8. BTEX and TPH Concentrations in Extracted Groundwater During the Bioslurper Pump Test at Wurtsmith AFB, MI

Parameter	Concentration (mg/L)				
	WUR-H_2O-1	WUR-H_2O-2	WUR-H_2O-3	WUR-H_2O-4	WUR-H_2O-5
TPH (Purgeable)	9.6	2.2	3.5	5.1	2.2
Benzene	0.033	0.040	0.037	0.035	0.035
Toluene	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010
Ethylbenzene	0.043	0.019	0.017	0.020	0.021
Total Xylenes	0.19	0.14	0.12	0.14	0.14

separator, and clarification tanks, resulted in water effluent (2.2 to 9.6 mg/L total hydrocarbons) that is considered compatible with typical sanitary sewer discharge limits.

The results from the off-gas analyses are presented in Table 9. All extracted soil gas was reinjected at the site. Given a vapor reinjection rate of 2 L/min and using an average concentration of 4,600 ppmv TPH and 21 ppmv benzene, approximately 0.18 lb/day[1] of TPH and 0.00020 lb/day of benzene were emitted to the air. Thus, mass removal in the vapor phase is not significant. Higher vapor mass removal rates are more often sustained at those sites where liquid product recovery is sustained.

The composition of LNAPL is shown in Table 10 and 11 in terms of BTEX concentrations and distribution of C-range compounds, respectively. The distribution of C-range compounds also is shown graphically in Figure 10.

4.4 Bioventing Analyses

4.4.1 Soil Gas Permeability and Radius of Influence

The radius of influence is calculated by plotting the log of the pressure change at a specific monitoring point versus the distance from the extraction well. The radius of influence is then defined as the distance from the extraction well where 0.10 inch of H_2O can be measured. Based on this definition, the radius of influence during the bioslurper pump test at H192S was approximately 54 ft (Figure 11). Only the pressure change at the deepest depths was used to determine the radius of influence. No significant pressure change difference was observed between the shallow depths.

4.4.2 In Situ Respiration Test Results

Results from the in situ respiration test are presented in Table 12. Oxygen utilization rates were relatively low, ranging from 0.060 to 0.10 $\%O_2$/hr. Biodegradation rates ranged from 0.94 to 1.6 mg/kg-day. These results indicate that biodegradation in these locations is significant and that bioventing is feasible at this site.

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[1] This value was calculated based on an average molecular weight of 147 from the carbon range analysis. This calculation assumes straight chain compounds.

Table 9. BTEX and TPH Concentrations in Off-Gas During the Bioslurper Pump Test at Wurtsmith AFB, MI

Parameter	Concentration (ppmv)		
	WUR-REINJECT 1[2]	WUR-REINJECT 2	WUR-REINJECT 3
TPH as jet fuel	5,600	3,600	540
Benzene	12.0	30.0[1]	1.2
Toluene	40.0	69.0	11.0
Ethylbenzene	7.9	22.0	2.6
Xylenes	26.0	75.0	12.0

1 Reported value may be biased due to apparent matrix interferences.

Table 10. BTEX Concentrations in LNAPL from Wurtsmith AFB, MI

Compound	Concentrations (mg/kg)
Benzene	<440
Toluene	<440
Ethylbenzene	<440
Total Xylenes	10,000

Table 11. C-Range Compounds in LNAPL from Wurtsmith AFB, MI

C-Range Compound	Percentage of Total
<C9	32.72
C10	17.49
C11	13.00
C12	10.74
C13	7.97
C14	5.98
C15	3.37
C16	2.02
C17	1.63
C18	1.25
C19	0.95
>C20	2.87

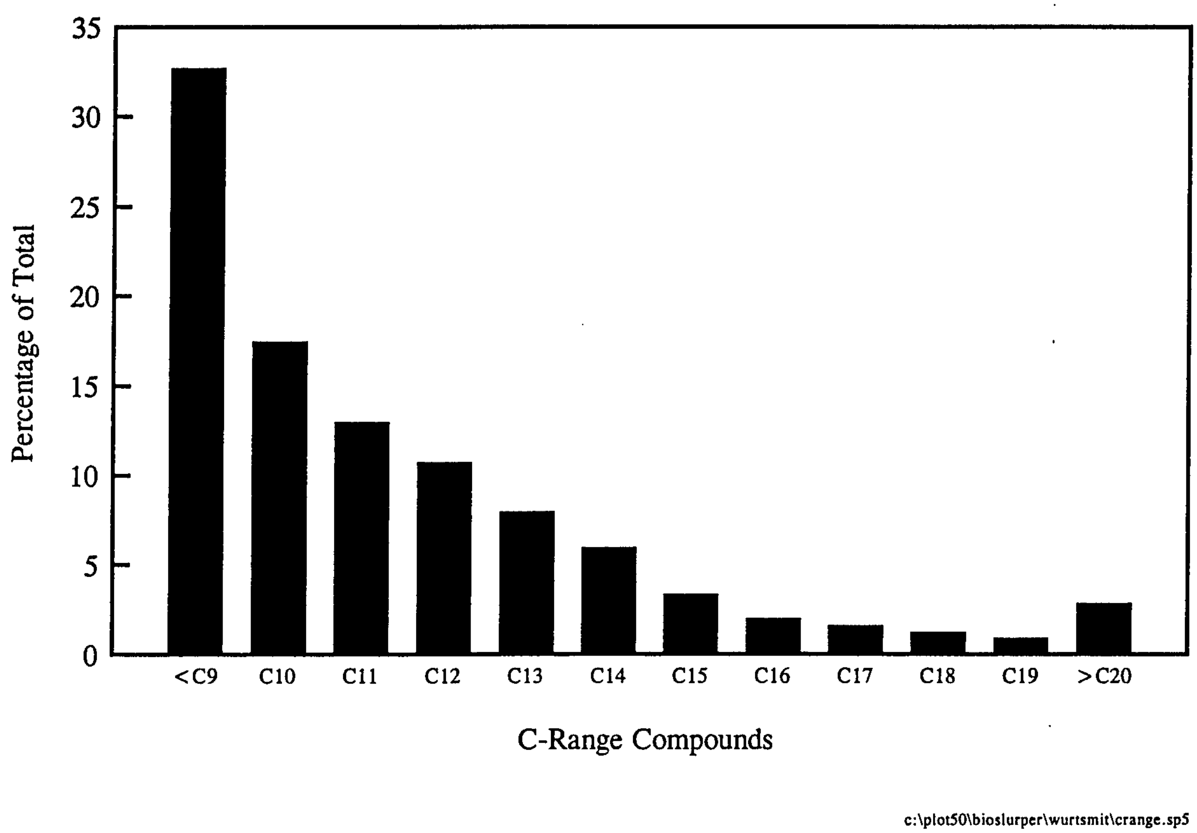

Figure 10. Distribution of C-Range Compounds in Extracted LNAPL at Wurtsmith AFB, MI

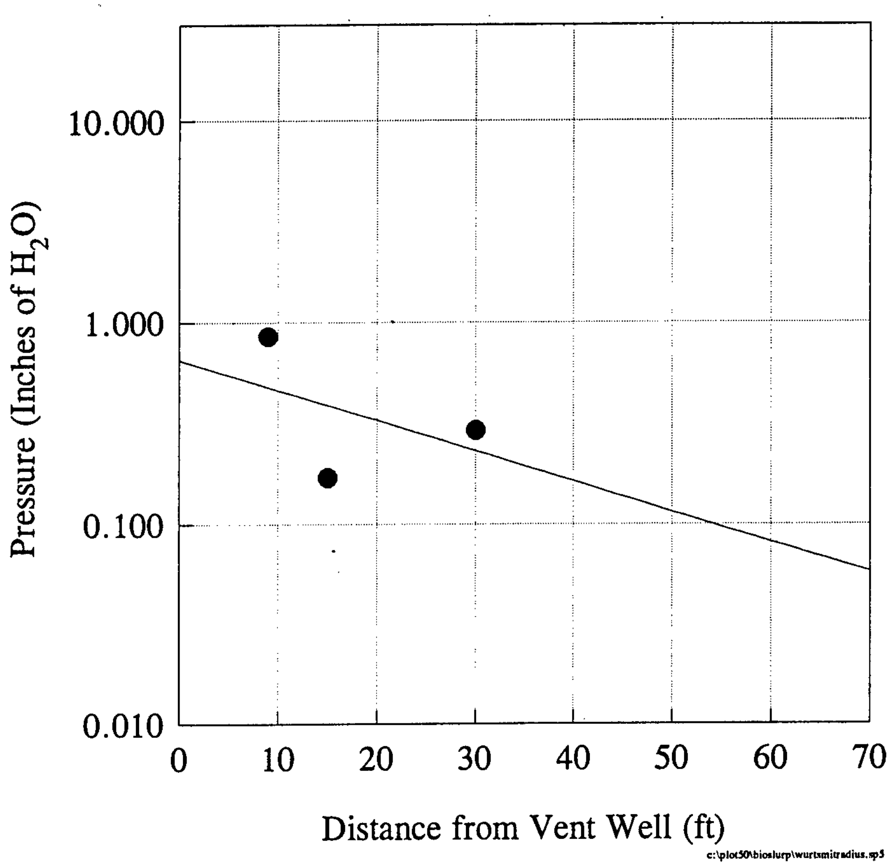

Figure 11. **Soil Gas Pressure Change as a Function of Distance During the Soil Gas Permeability Test at Monitoring Well H192S**

Table 12. In Situ Respiration Test Results at Site SS-06, Wurtsmith AFB, MI

Monitoring Point	Oxygen Utilization Rate (%/hr)	Biodegradation Rate (mg/kg-day)
WU-MPA-21.0	0.10	1.6
WU-MPB-21.0	0.080	1.3
WU-MPC-21.0	0.060	0.94

4.4.3 Surface Emissions Results

Results of surface emissions analysis are shown in Table 13. Analysis demonstrates that surface emissions were negligible, with average TPH surface emissions of 50 lb/acre/day and average benzene emissions of 0.029 lb/acre/day.

5.0 DISCUSSION AND CONCLUSIONS

The main objective of the field pilot test at Site SS-06, Wurtsmith AFB was to determine if LNAPL recovery is feasible and to select the most effective method of LNAPL recovery.

Baildown recovery tests were conducted at monitoring wells H196S and H192S. Baildown recovery tests provide a qualitative indication of the presence of mobile, free-phase LNAPL and recovery potential. Overall, the baildown recovery tests indicated a moderate rate of LNAPL recovery into the wells. At monitoring well H192S, LNAPL recovered to approximate initial levels by the end of the 28 hr baildown test. At monitoring well H196S, LNAPL recovered to a level approximately ⅓ of the initial LNAPL thickness. Based on these results, pilot testing was initiated on monitoring well H192S.

Direct pumping tests were conducted at monitoring wells H192S and H196S. Skimmer pump testing was conducted at monitoring well H192S in a continuous extraction mode for two days. Minimal quantities of free-phase LNAPL was recovered during the two days of skimmer pump testing, indicating that gravity-driven recovery is minimal. Bioslurper testing was conducted for four days resulting in relatively low recovery on the first day (2.3 gallons/day), followed by steadily

Table 13. Surface Emissions Sampling Results at Wurtsmith AFB, MI

Sample	Flux Values (lb/acre/day)					
	Benzene	Toluene	Ethylbenzene	*m&p* Xylene	*o*-Xylene	TPH
Wur-SGE-1	0.0082	0.57	0.67	0.78	0.49	51
Wur-SGE-2	0.049	1.1	0.29	0.18	0.058	49
Ambient	<5.1E-05	<5.1E-05	<5.1E-05	<5.1E-05	<5.1E-05	<5.1E-05
Trip blank	<5.1E-05	<5.1E-05	<5.1E-05	<5.1E-05	<5.1E-05	<5.1E-05
Cylinder	<5.1E-05	<5.1E-05	<5.1E-05	<5.1E-05	<5.1E-05	<5.1E-05

dropping recovery rates. The LNAPL recovery rate dropped to 0.40 gallons/day by hour 63. At this point, the pump vacuum was increased to full vacuum, and a slight increase in LNAPL recover was observed (0.71 gallons/da); however, recovery dropped to 0 by day 4. The loss of LNAPL recovery is likely due to the drop in the vapor extraction rate. Groundwater production rates during bioslurping were higher than rates during the drawdown pump test, indicating that vacuum enhanced fluid recovery was in effect during the bioslurper pump test. The on-site water treatment equipment, consisting of a filter tank, oil/water separator, and clarification tanks, resulted in water effluent (2.2 to 9.6 mg/L total hydrocarbons) that is considered compatible with typical sanitary sewer discharge limits.

Drawdown testing was conducted to determine if a cone of groundwater depression would enhance LNAPL recovery. The water table was depressed in monitoring well H192S 5 inches below the static water table. No measurable LNAPL free product was recovered in this mode during one day of continuous extraction. Groundwater recovery rates were on the order of 1,900 gallons/day. Based on these results, the vacuum gradient maintained during the bioslurper pump test resulted in higher fluid recovery rates than the 5 inch-groundwater drawdown test.

In an effort to determine if the results at monitoring well H192S were representative of site conditions, bioslurper testing was conducted at monitoring well H196S. Minimal free-phase LNAPL was recovered during the half day of bioslurper pumping (2.2 gallons/day). The well head vacuum on monitoring well H196S (2.5"H_2O) and groundwater production rate (5,000 gallons/day) were similar to those observed at monitoring well H192S. Results at monitoring wells H192S and H196S appear to be representative of the site and indicate that gravity-driven liquid recovery techniques are not feasible and that vacuum-enhanced recovery is minimal.

Bioslurping also promotes mass removal in the form of in situ biodegradation via bioventing and soil gas extraction. Vapor phase mass removal is the result of soil gas extraction as well as volatilization that occurs during the movement of LNAPL free product through the extraction network. Given, the measured vapor flowrate (2 L/min) and vapor concentrations, initial hydrocarbon removal rates were approximately 0.18 lb/day of TPH and 0.00020 lb/day of benzene. Thus, initially, mass removal in the vapor phase is not significant.

The initial soil gas profiles at the site displayed oxygen-deficient, carbon dioxide-rich, high total volatile hydrocarbon vapor conditions at depths greater than 16 ft, although some oxygen limitation was observed at shallower depths. These conditions indicate that natural biodegradation of residual petroleum hydrocarbons has occurred, but is limited by oxygen availability. Soil gas concentrations were measured during the bioslurper test at monitoring points adjacent to monitoring well H192S to determine if the vadose zone was being oxygenated via the bioslurper action. Soil gas concentrations were measured during the bioslurper test at monitoring points adjacent to monitoring well H192S to determine if the vadose zone was being oxygenated via the bioslurper action. Oxygen concentrations were influenced at all monitoring point, with oxygen concentrations in soil gas ranging from 16 to 20% by the end of the bioslurper pump test. These results correlate with the soil gas permeability test, where a radius of influence of 54 ft was measured. In situ biodegradation rates 0.94 of to 1.6 mg/kg-day were measured at three different locations. Based on the radius of influence of 54 ft and a hydrocarbon-impacted soil thickness of 28 ft, mass removal rates via biodegradation are on the order of 21 to 36 lbs of hydrocarbon per day. Thus, mass removal rates via biodegradation could be as significant as the vapor phase removal rates measured during the bioslurper test. These results indicate that bioventing is feasible at this site. Air injection bioventing is preferable over bioslurping and soil vapor extraction with respect to the elimination of hydrocarbon vapor emissions.

In summary, the on-site testing at Site SS-06, Wurtsmith AFB, included the direct testing of gravity-driven and vacuum-driven LNAPL free product recovery techniques, bioventing, physical sampling, and tests relevant to soil vapor extraction. Liquid phase recovery was only sustainable under vacuum-enhanced conditions, although recovery was low. The vacuum-enhanced mode is significant in that if liquid phase LNAPL recovery is not sustainable under high vacuum conditions, then it is unlikely that it will be sustainable under any conditions. The in situ respiration test and vadose zone radius of influence testing demonstrate that bioventing may be feasible at this site.

Bioslurping appears to be a suitable recovery technique for this site. The loss of LNAPL recovery at full vacuum may be avoided by installing wells that are more suited for bioslurping. The monitoring wells used were screened below the water table, and as such, probably limited the amount of free product which could be recovered.

6.0 REFERENCES

Battelle, 1995. *Test Plan and Technical Protocol for Bioslurping*. Report prepared by Battelle Columbus Operations for the U.S. Air Force Center for Environmental Excellence, Brooks Air Force Base, Texas.

Hinchee, R.E., S.K. Ong, R.N. Miller, D.C. Downey, and R. Frandt. 1992. *Test Plan and Technical Protocol for a Field Treatability Test for Bioventing* (Rev. 2). Report prepared by Battelle Columbus Operations, U.S. Air Force Center for Environmental Excellence, and Engineering Sciences, Inc., for the U.S. Air Force Center for Environmental Excellence, Brooks Air Force Base, Texas.

APPENDIX A

SITE-SPECIFIC TEST PLAN FOR BIOSLURPER FIELD ACTIVITIES AT WURTSMITH AFB, MICHIGAN

SITE-SPECIFIC TEST PLAN FOR BIOSLURPER TESTING AT WURTSMITH AIR FORCE BASE, MICHIGAN CONTRACT NO. F41624-94-C-8012

FINAL

to

Air Force Center for Environmental Excellence
Technology Transfer Division
(AFCEE/ERT)
8001 Arnold Drive
Building 642
Brooks AFB, Texas 78235

and

Wurtsmith Air Force Base, Michigan

22 July 1996

by

Battelle
505 King Avenue
Columbus, Ohio 43201-2693

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ACRONYMS AND ABBREVIATIONS

AFB	Air Force Base
AFCEEE	Air Force Center for Environmental Excellence
bgs	below ground surface
BTEX	benzene, toluene, ethylbenzene, and xylenes
JP	jet propulsion (fuel)
LNAPL	light, nonaqueous-phase liquid
POC	Point of Contact
PoL	Petroleum, Oil, and Lubricant
TPH	total petroleum hydrocarbons
USGS	U.S. Geological Survey

SITE-SPECIFIC TEST PLAN FOR BIOSLURPER TESTING AT WURTSMITH AIR FORCE BASE, MICHIGAN

FINAL

to

Air Force Center for Environmental Excellence
Technology Transfer Division
(AFCEE/ERT)
Brooks AFB, Texas 78235-5357

22 July 1996

1.0 INTRODUCTION

The U.S. Air Force Center for Environmental Excellence (AFCEE) Technology Transfer Division is conducting a nationwide application of an innovative technology for free-product recovery and soil bioremediation. The technologies tested in the Bioslurper Initiative include vacuum-enhanced free-product recovery/bioremediation (bioslurping) as well as traditional skimmer and groundwater depression approaches. The field test and evaluation are intended to demonstrate the feasibility of free-product recovery by measuring system performance in the field. System performance parameters, mainly free-product recovery, will be determined at numerous sites. Field testing will be performed at many sites to determine the effects of different organic contaminant types and concentrations and different geologic conditions on bioslurping effectiveness.

Plans for the field test activities are presented in two documents. The first is the overall Test Plan and Technical Protocol for the entire program entitled *Test Plan and Technical Protocol for Bioslurping* (Battelle, 1995). The overall plan is supplemented by plans specific to each test site. The concise site-specific plans effectively communicate planned site activities and operational parameters.

The overall Test Plan and Technical Protocol was developed as a generic plan for the Bioslurper Initiative to improve the accuracy and efficiency of site-specific Test Plan preparation. The field program involves installation and operation of the bioslurping system supported by a wide variety of site characterization, performance monitoring, and chemical analysis activities. The basic methods to be applied from site to site do not change. Preparation and review of the overall Test Plan and Technical Protocol allows efficient documentation and review of the basic approach to the test program. Peer and regulatory review were performed for the overall Test Plan and Technical Protocol to ensure the credibility of the overall program.

This document is the site-specific Test Plan for application of bioslurping at Wurtsmith Air Force Base (AFB), Michigan. It was prepared based on site-specific information received by Battelle from Wurtsmith AFB and other pertinent site-specific information to support the overall Test Plan and Technical Protocol.

Site-specific information for Wurtsmith AFB has identified subsurface hydrocarbon contamination at the Petroleum, Oil, Lubricant (POL) Bulk Storage Area (SS-06). The contamination is generally associated with JP-4 jet fuel, which is thought to have leaked from an aboveground storage tank previously located at the site. Free product, as light, nonaqueous-phase liquid (LNAPL), has been measured in the vicinity of the former storage tank at thicknesses of approximately 1 to 2 ft. The greatest free-product thicknesses in July 1996 were found at H192S and H196S; however, these wells appear to be screened approximately 15 ft below the water table and may not be appropriate for the bioslurper pilot test.

2.0 SITE DESCRIPTION

The information presented in this section was obtained from *The United States Air Force Installation Restoration Program Second Draft RI/FS Work Plan: IRP Sites SS-06, ST-40 and SS-13* prepared for the U.S. Air Force Center for Environmental Excellence by ICF Technology Incorporated, June 1994.

Wurtsmith AFB is located in the northeastern portion of Michigan's lower peninsula in Iosco County and occupies an area of 5,221 acres. Wurtsmith AFB lies nearest to the city of Oscoda and is located less than 1 mile west of Lake Huron. The installation is bounded by Huron National Forest to the south, by Alpena State Forest to the west, and by man-made Van Etten Lake to the northeast. The proposed site for bioslurper activities is the POL Bulk Storage Area (SS-06), which is located in the east-central portion of Wurtsmith AFB (Figure 1).

Contamination at the site is associated with JP-4 jet fuel which was formerly stored in a 1.2-million-gallon aboveground storage tank identified as Tank 7,000. Contamination is likely to have resulted from leakage of this tank, which has since been drained and removed. There are no records of any major spills having occurred at the site.

Benzene, toluene, and organic compounds were first detected in the groundwater in 1979, and contamination as free floating product was found in 1983. As a result, an investigation was conducted by the U.S. Geological Survey (USGS) involving the installation of 8 shallow and 4 deep monitoring wells (Figure 2). A Benzene Pump and Treat Plant has been in operation since 1992 to remediate groundwater and remove free-floating product. The Benzene Plant consists of 4 purge wells and 2 air-stripper towers and operates in conjunction with a free-product recovery system.

The site geology consists of a layer of medium-grained sands from the surface to 70 ft below ground surface (bgs) interspersed with occasional silty-clay lenses. Thin gravel lenses are found rarely at the lower boundary of this unit. A silty-clay unit with an estimated thickness of 100 ft or greater underlies the unconsolidated glacial sediments. Units below this are unaffected by surface contamination. A geologic cross section can be found in Appendix A.

The depth to groundwater at Wurtsmith AFB ranges from 3 to 25 ft bgs with water table elevations fluctuating approximately 1 to 3 ft annually. A large number of wells near the Benzene Pump and Treat Plant are screened at intervals below the oil/water interface and do not always account for water table fluctuations that occur as a result of seasonal variations. The aquifer corresponds with the sandy unit and extends to the silty-clay aquitard referred to above. A deeper aquifer exists; however, it seems to be isolated from the surficial hydrocarbon contamination.

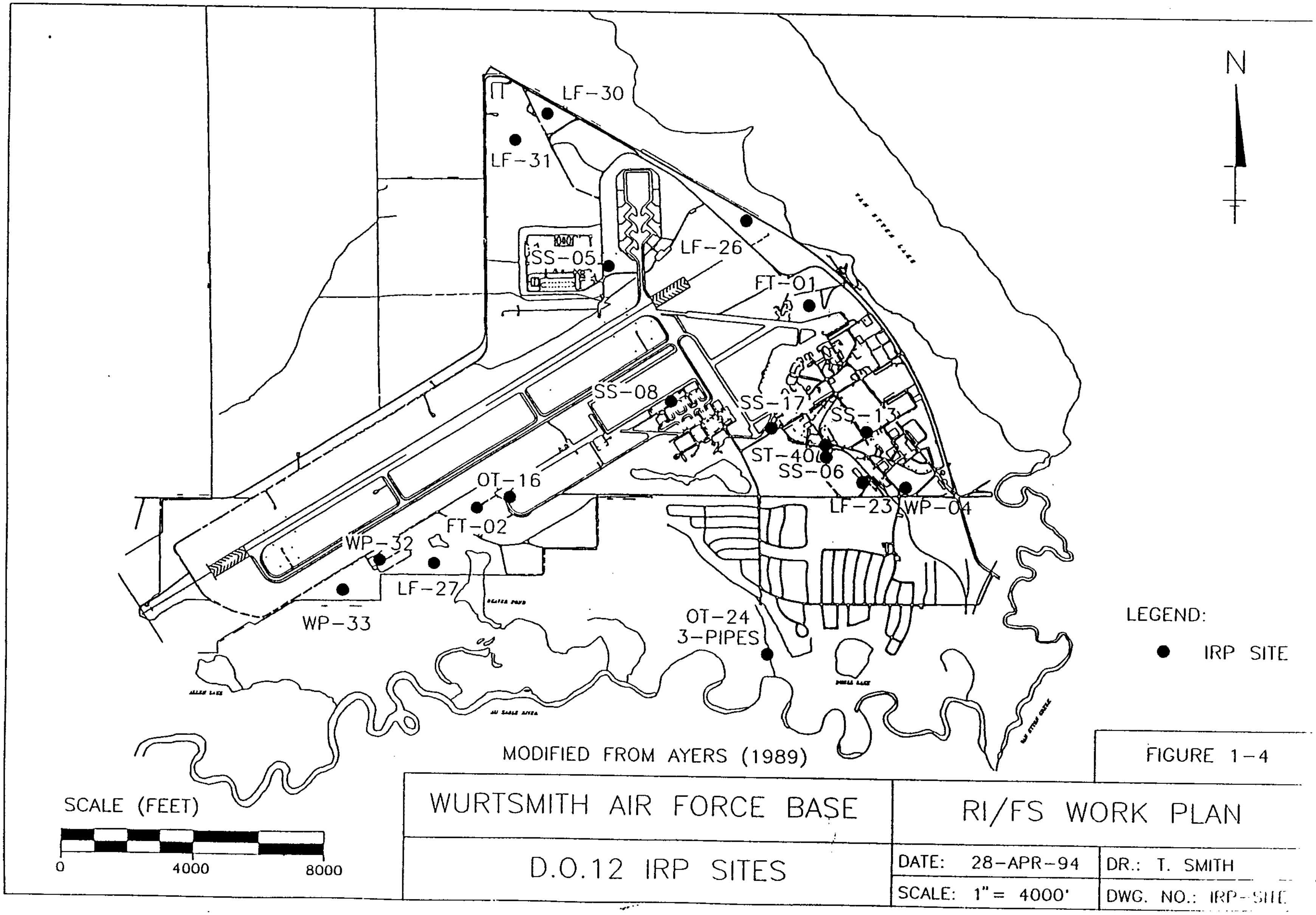

Figure 1. Location Map of SS-06, Wurtsmith AFB, Michigan

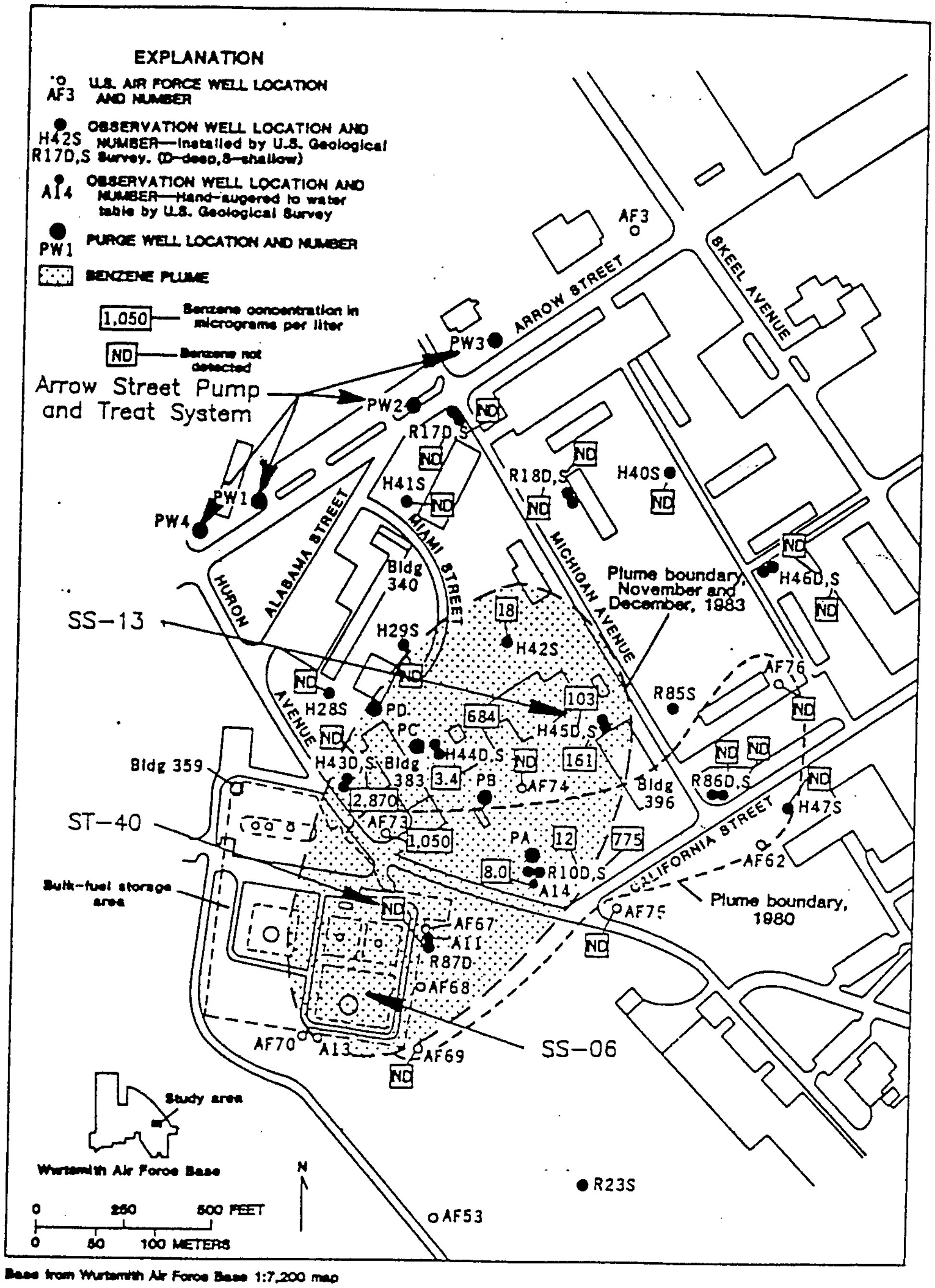

FIGURE 2-7

WURTSMITH AIR FORCE BASE	BLOCK C RI/FS WORK PLAN SITE SS-06	
1983 BENZENE PLUME	DATE: 01/07/94	DR.:
	SCALE: AS SHOWN	FILE NAME: BENZ9

Figure 2. Schematic Diagram of Benzene Plume at SS-06, Wurtsmith AFB, Michigan (Source: ICF Technology Inc., 1994)

Groundwater in the vicinity of SS-06 flows northeast toward Van Etten Creek and Van Etten Lake; however, groundwater in the southern portion of the Base flows south to the Au Sable River (Figure 3). Extensive pumping involved in the operation of the Benzene Plant has resulted in a cone of depression in this area. The municipal water supply is separate from the groundwater system at the Base, and the Base itself is supplied with water from the city of Oscoda.

Since the Benzene Plant has been in operation, only a slight decrease in benzene concentrations in groundwater has been seen. This could be accounted for by plant operation at less than optimal rates or a plume that is larger than originally anticipated. Measurements taken in July 1996 reveal that floating free product still exists in numerous wells at depths up to approximately 1 ft (Table 1). The well locations are shown in Figure 4. Construction details and free product thicknesses are summarized in Appendix B.

TABLE 1. FREE PRODUCT THICKNESSES AT SITE SS-06, WURTSMITH AFB, MICHIGAN.

Well ID	Depth to Product (ft)	Depth to Water (ft)	Product Thickness
H190S	--	24.82	0.00
H191S	26.40	26.54	0.14
H192S	27.32	28.44	1.12
H193S	26.38	26.40	0.02
H194S	27.73	27.76	0.03
H195S	27.88	27.95	0.07
H196S	28.02	28.33	0.31

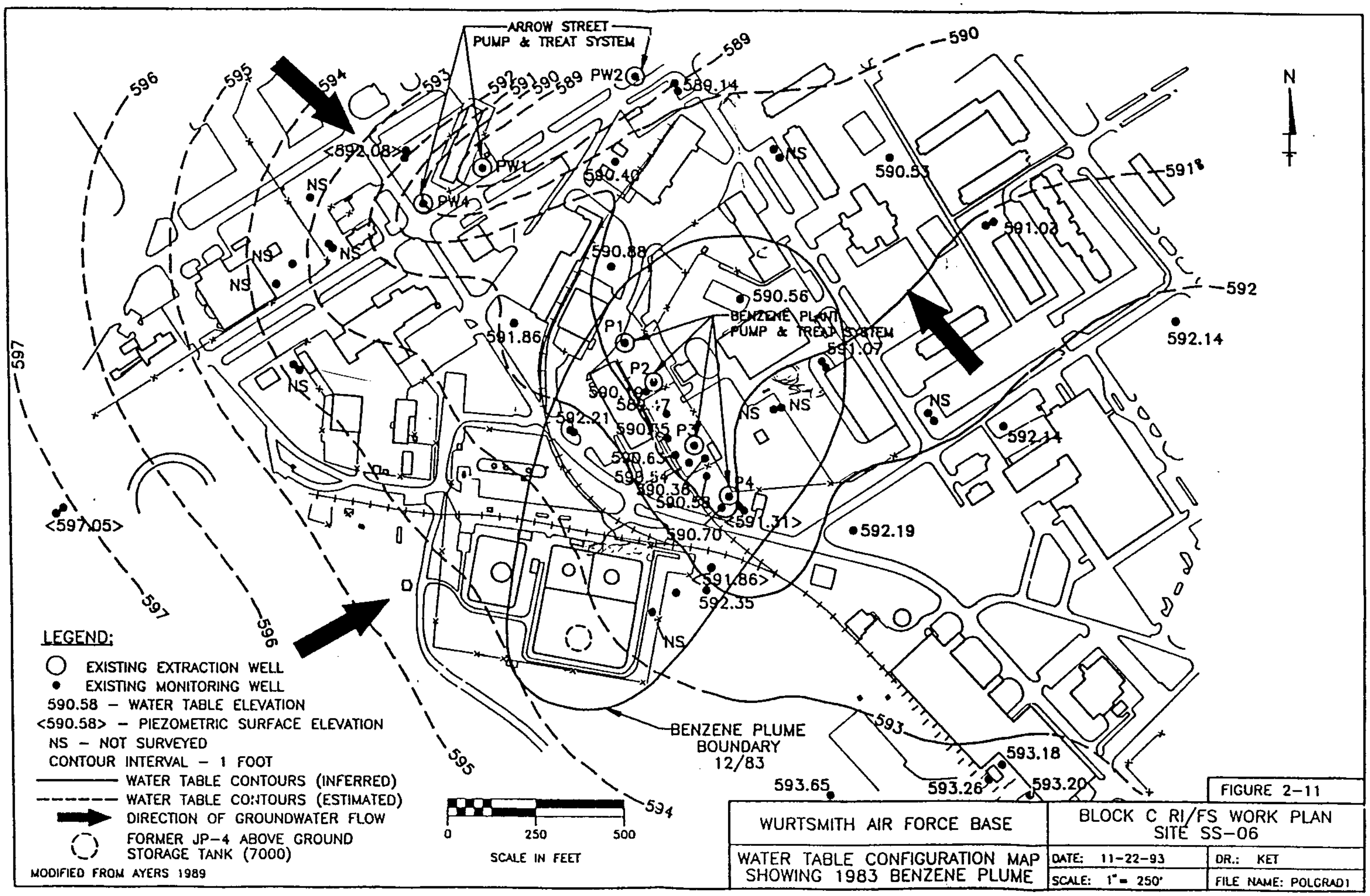

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Figure 3. Schematic Diagram of Groundwater Elevation and Flow Direction at Wurtsmith AFB, Michigan

SITE MAP

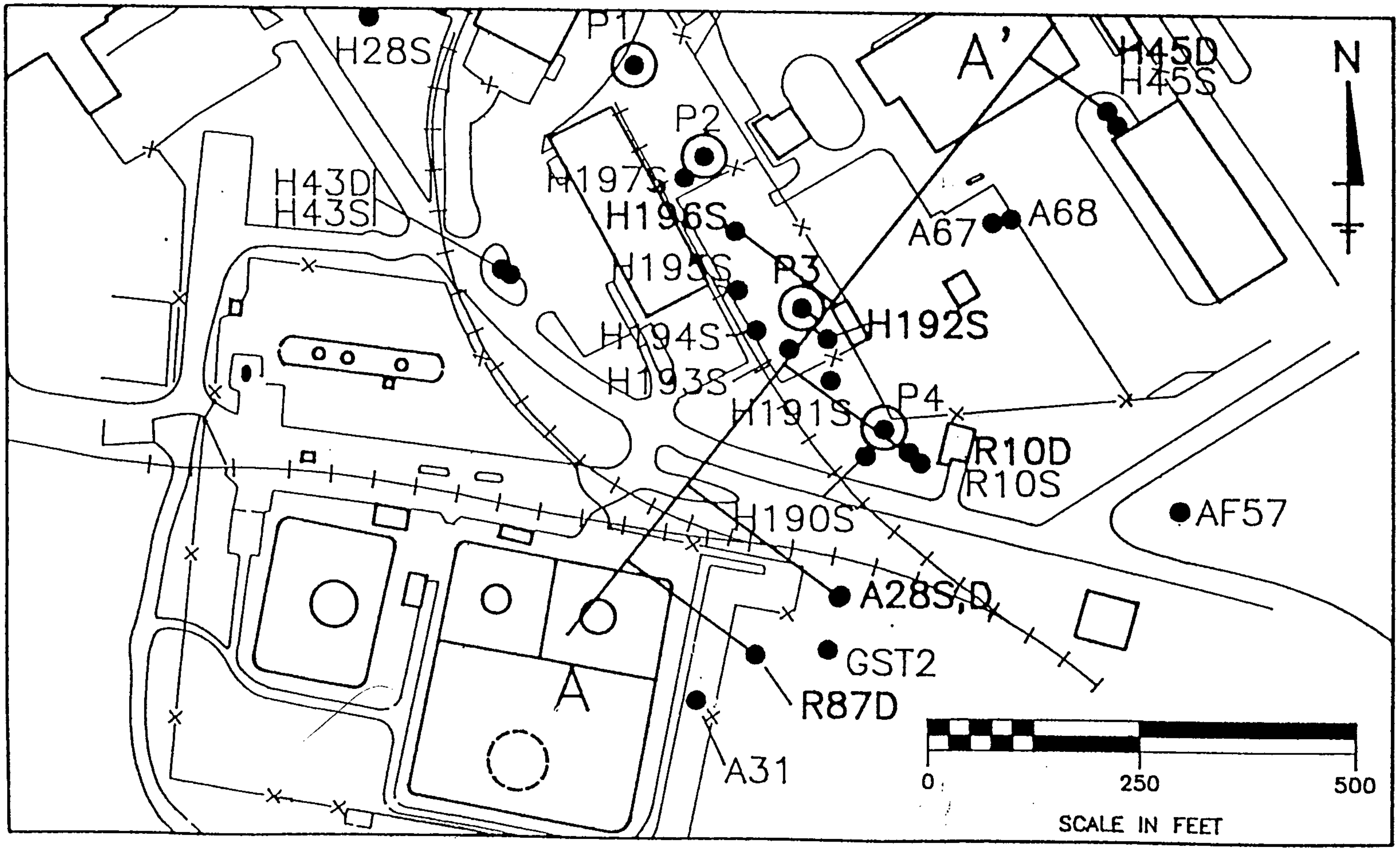

Figure 4. Schematic Diagram of Well Locations at SS-06, Wurtsmith AFB, Michigan

3.0 PROJECT ACTIVITIES

The field activities discussed in the following sections are planned for the bioslurper pilot test at Wurtsmith AFB. Additional details about the activities are presented in the overall Test Plan and Technical Protocol (Battelle, 1995). As appropriate, specific sections in the overall Test Plan and Technical Protocol are referenced. Table 2 presents the schedule of activities for the Bioslurper Initiative at Wurtsmith AFB.

3.1 Mobilization to the Site

After the site-specific Test Plan is approved, Battelle staff will mobilize equipment to the site. Some of the equipment will be shipped via air express to Wurtsmith AFB prior to staff arrival. The Base Point of Contact (POC) will have been asked in advance to find a suitable holding facility to receive the bioslurper pilot test equipment so that it will be easily accessible to the Battelle staff when they arrive with the remainder of the equipment. The exact mobilization date will be confirmed with the Base POC as far in advance of fieldwork as is possible. The Battelle POC will provide the Base POC with information on each Battelle employee who will be on site. Battelle personnel will be mobilized to the site after confirmation that the shipped equipment has been received by Wurtsmith AFB.

3.2 Site Characterization Tests

3.2.1 Baildown Tests

The baildown test is the primary test for selection of the bioslurper test well. Baildown tests are also useful for the evaluation of actual versus apparent free-product thicknesses. Baildown tests will be performed at wells that contain measurable thicknesses of LNAPL to estimate the LNAPL recovery potential at those particular wells. In most cases, the well exhibiting the highest rate of LNAPL recovery will be selected for the bioslurper extraction well. A sample of free LNAPL will be collected at this point for analyses of boiling point distribution and concentrations of benzene, toluene, ethylbenzene, and xylenes (BTEX). Detailed procedures for the baildown tests are provided in Section 5.6 of the overall Test Plan and Technical Protocol (Battelle, 1995).

TABLE 2. SCHEDULE OF BIOSLURPER PILOT TEST ACTIVITIES

Pilot Test Activity	Schedule
Mobilization	Day 1-2
Site Characterization LNAPL/Groundwater Interface Monitoring and Baildown Tests Soil Gas Survey (Limited) Monitoring Point Installation (3 monitoring points) Soil Sampling (BTEX, TPH, physical characteristics)	Day 2-3
System Installation	Day 2-3
Test Startup	Day 3
Skimmer Pump Test (2 days)	Day 3-4
Bioslurper Pump Test (4 days)	Day 5-8
Soil Gas Permeability Testing	Day 5
Skimmer Pump Test (continued)	Day 9
In Situ Respiration Test - Air/Helium Injection	Day 9
In Situ Respiration Test - Monitoring	Day 10-13
Drawdown Pump Test (2 days)	Day 10-11
Demobilization/Mobilization	Day 12-13

3.2.2 Monitoring Point Installation

Monitoring points must be installed to determine the radius of influence of the bioslurper system in the vadose zone. A general arrangement of the bioslurping well and monitoring points is shown in Figure 5. Upon completion of the initial soil gas survey and baildown tests, at least three soil gas monitoring points will be installed (unless existing monitoring points are available for use) to measure soil gas changes that occur during bioslurper operation. These monitoring points should be located in highly contaminated soils within the free-phase plume and should be positioned to allow detailed monitoring of the in situ changes in soil gas composition caused by the bioslurper system. A schematic diagram of a typical monitoring point is shown in Figure 6. Information on monitoring point installation can be found in Section 4.2.1 of the overall Test Plan and Technical Protocol (Battelle, 1995).

3.2.3 Soil Sampling

Soil samples will be collected from each boring to determine the physical and chemical composition of the soil near the bioslurper test site. Soil samples will be collected from the boreholes advanced for monitoring point installation at one or two locations at the site chosen for the bioslurper test. Generally, samples will be collected from the capillary fringe over the free product.

Soil samples from each boring will be analyzed for BTEX, bulk density, moisture content, particle size distribution, porosity, and total, petroleum hydrocarbon (TPH). Section 5.5.1 of the overall Test Plan and Technical Protocol (Battelle, 1995) contains additional information on field measurements and sample collection procedures for soil sampling.

3.3 Bioslurper System Installation and Operation

Once the well to be used for the bioslurper test installation at Wurtsmith AFB has been identified, the bioslurper pump and support equipment will be installed and pilot testing will be initiated.

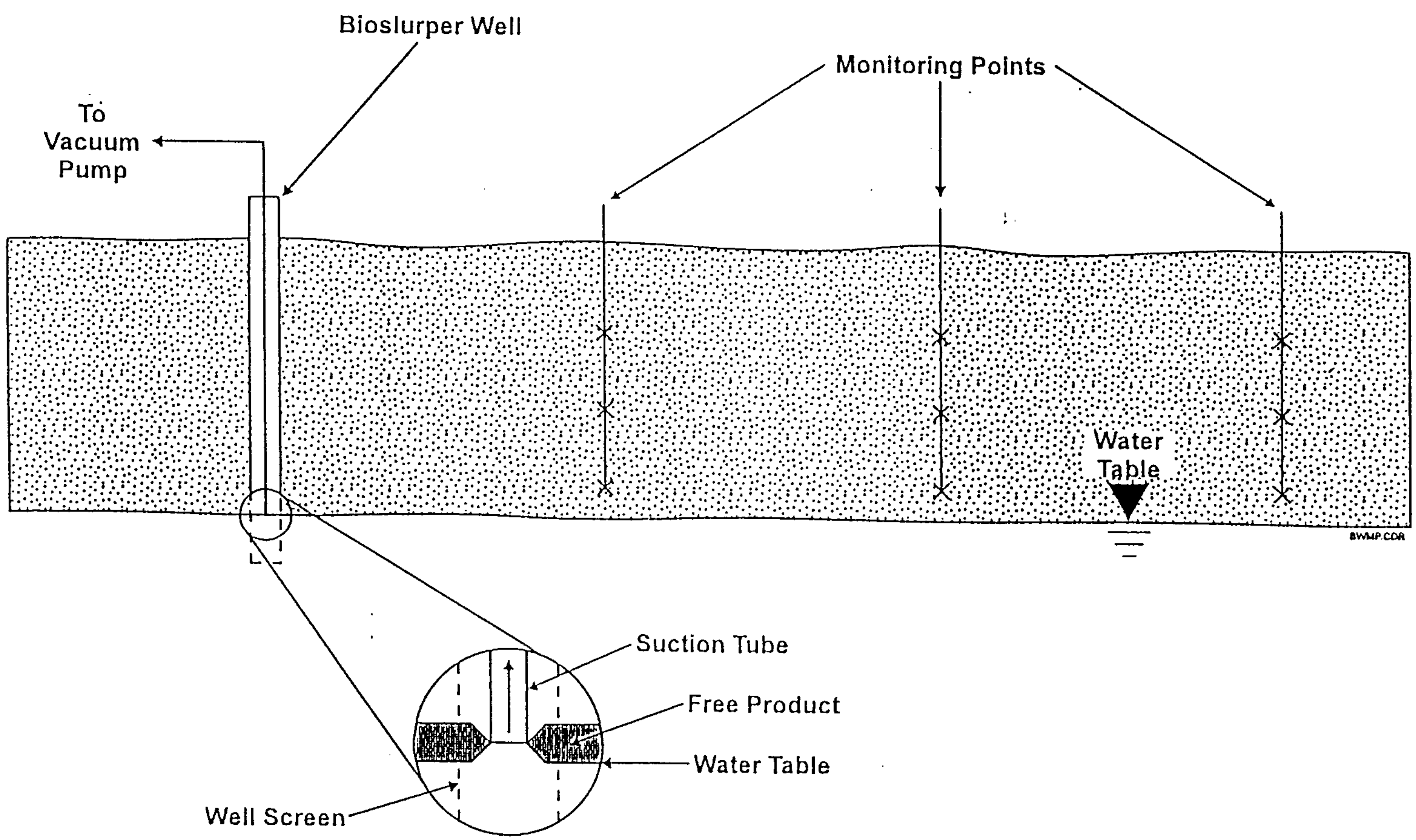

Figure 5. General Bioslurper Well and Monitoring Point Arrangement.

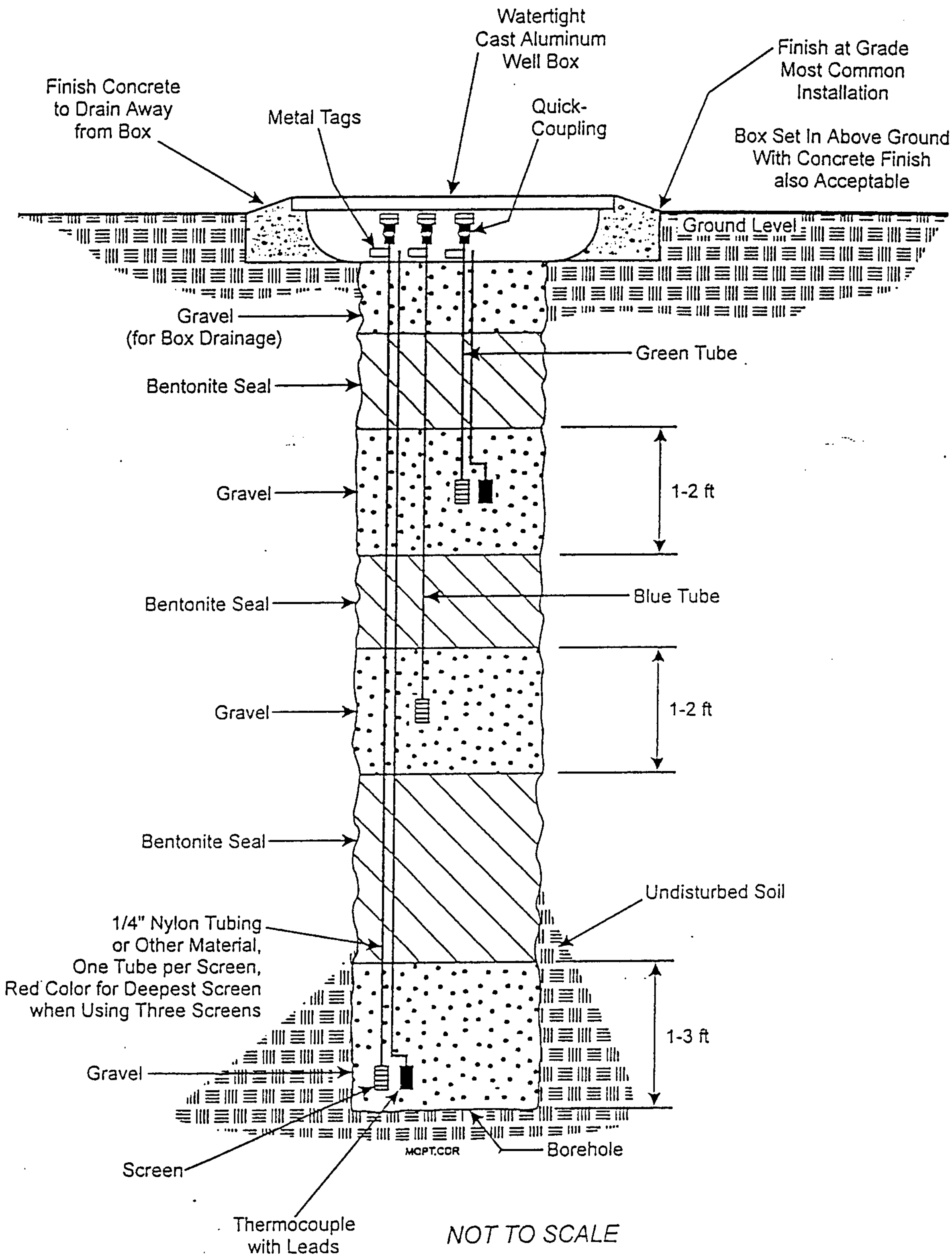

Figure 6. Schematic Diagram of a Typical Monitoring Point.

3.3.1 System Setup

After the preliminary site characterization has been completed and the bioslurper candidate well has been selected, the shipped equipment will be mobilized from the holding facility to the test site, and the bioslurper system will be assembled. Figure 7 shows a flow diagram of the bioslurper process. Figure 8 illustrates a typical bioslurper well that will be used at Wurtsmith AFB.

Before the LNAPL recovery tests are initiated, all relevant baseline field data will be collected and recorded. These data will include soil gas concentrations, initial soil gas pressures, the depth to groundwater, and the LNAPL thickness. Ambient soil and all atmospheric conditions (e.g., temperature, barometric pressure) also will be recorded. All emergency equipment (i.e., emergency shutoff switches and fire extinguishers) will be installed and checked for proper operation at this time.

A clear, level 20-ft by 10-ft area near the well selected for the bioslurper test installation will be identified to station the equipment required for bioslurper system operation. Additional information on bioslurper system installation is provided in Section 6.0 of the overall Test Plan and Technical Protocol (Battelle, 1995).

3.3.2 System Shakedown

A brief startup test will be conducted to ensure that the system is constructed properly and operates safely. All system components will be checked for problems and/or malfunctions. A checklist will be provided to document the system shakedown.

3.3.3 System Startup and Test Operations

After installation is complete and the bioslurper system is confirmed to be operating properly, the LNAPL recovery tests will be started. The Bioslurper Initiative has been designed to evaluate the effectiveness of bioslurping as an LNAPL recovery test technology relative to conventional gravity-driven LNAPL recovery technologies. The Bioslurper Initiative includes three separate LNAPL recovery tests: (1) a skimmer pump test, (2) a bioslurper pump test, and (3) a drawdown pump test. The three recovery tests are described in detail in Section 7.3 of the overall Test Plan and Technical Protocol (Battelle, 1995).

The bioslurper system operating parameters that will be measured during operation are vapor discharge, aqueous effluent, LNAPL recovery volume rates, vapor discharge volume rates, and

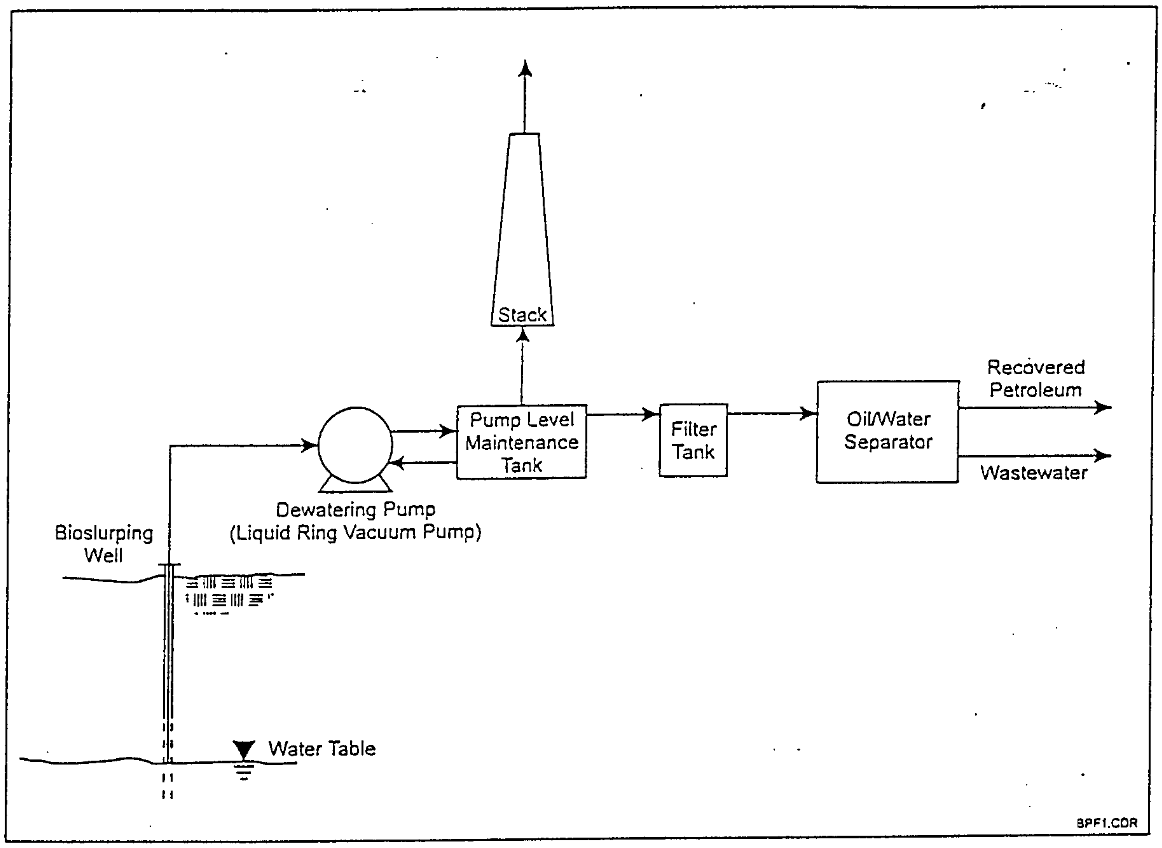

Figure 7. Bioslurper Process Flow at SS-06 Wurtsmith AFB, Michigan.

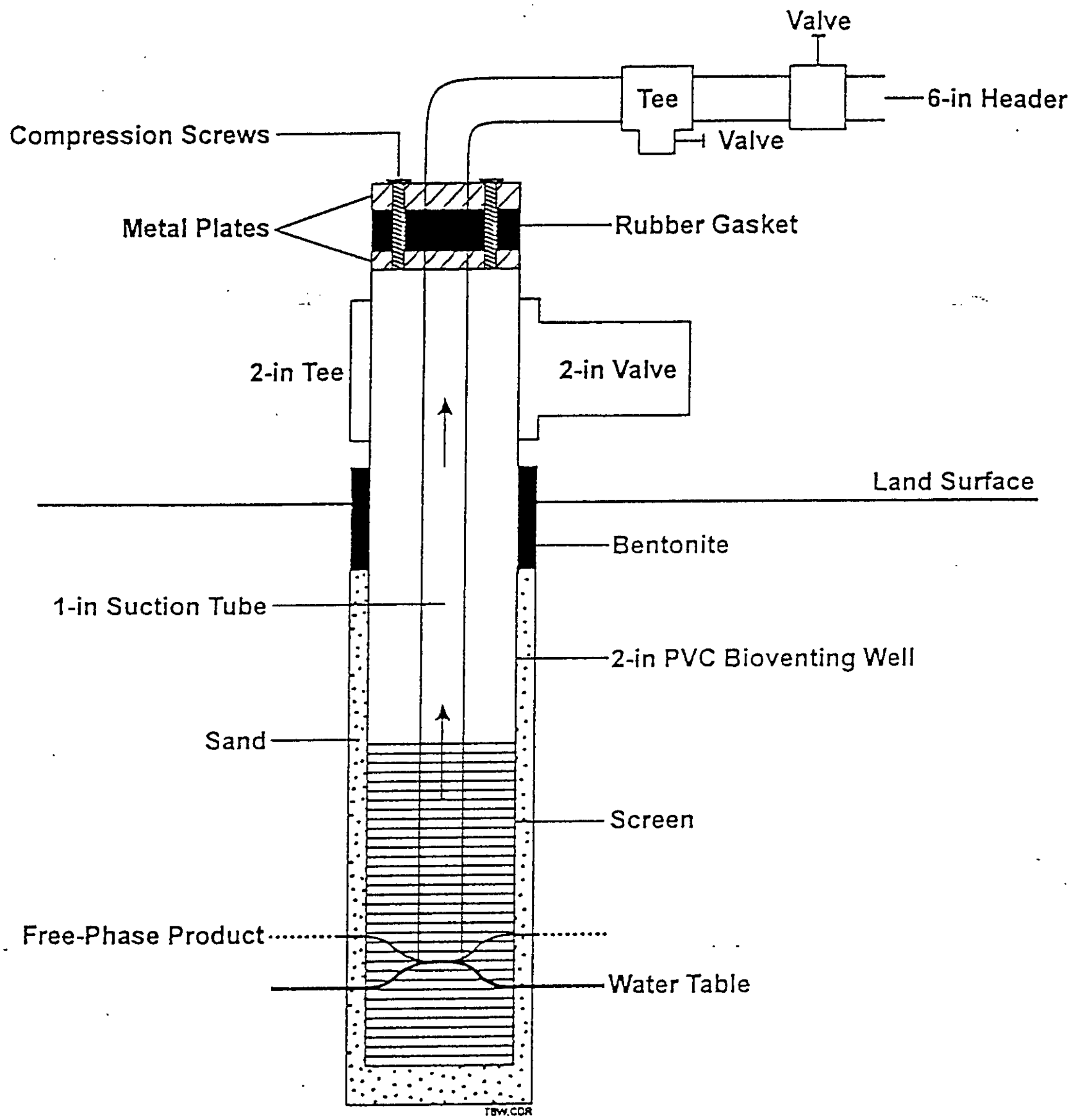

Figure 8. Schematic Diagram of a Typical Bioslurper Well.

groundwater discharge volume rates. Vapor monitoring will consist of periodic monitoring of TPH concentrations using hand-held instruments supplemented by two samples collected for detailed laboratory analysis. Two samples of aqueous effluent will be collected for analysis of BTEX and TPH. Recovered LNAPL volume will be recorded using an in-line flow-totalizing meter. The off-gas discharge volume will be measured using a calibrated pitot tube, and the groundwater discharge volume will be recorded using an in-line flow-totalizing meter. Section 8.0 of the overall Test Plan and Technical Protocol (Battelle, 1995) describes process monitoring of the bioslurper system.

3.3.4 Soil Gas Profile/Oxygen Radius of Influence Test

Changes in soil gas profiles will be measured before and during the bioslurper pump test. Soil gas will be monitored for concentrations of oxygen, carbon dioxide, and TPH using field instruments. These measurements will be used to determine the oxygen radius of influence of the bioslurper.

3.3.5 Soil Gas Permeability Tests

A soil gas permeability test will be conducted concurrently with startup of the bioslurper pump test. Soil gas permeability data will support the process of estimating the vadose zone radius of influence of the bioslurper system. Soil gas permeability results also will aid in determining the number of wells required if it is decided to treat the site with a full-scale bioslurper system. The soil gas permeability test method is described in Section 5.7 of the overall Test Plan and Technical Protocol (Battelle, 1995).

3.3.6 LNAPL and Groundwater Level Monitoring

During the bioslurper pump test, the LNAPL and groundwater levels will be monitored in a well adjacent to the extraction well if such a well exists. The top of the monitoring well will be sealed from the atmosphere so the subsurface vacuum will be contained. Additional information for the monitoring of fluid levels is provided in Section 4.3.4 of the overall Test Plan and Technical Protocol (Battelle, 1995).

3.3.7 In Situ Respiration Test

An in situ respiration test will be conducted after completion of the bioslurper pilot tests. The in situ respiration test will involve injection of air and helium into selected soil gas monitoring points followed by monitoring changes in concentrations of oxygen, carbon dioxide, TPH, and helium in soil gas at the injection point. Measurement of the soil gas composition typically will be conducted at 2, 4, 6, and 8 hours and then every 4 to 12 hours for about 2 days. Timing of the tests will be adjusted based on the oxygen-use rate. If oxygen depletion occurs rapidly, more frequent monitoring will be required. If oxygen depletion is slow, less frequent readings will be acceptable. The oxygen utilization rate will be used to estimate the biodegradation rate at the site. Further information on the procedures and data collection of the in situ respiration test is provided in Section 5.8 of the overall Test Plan and Technical Protocol (Battelle, 1995).

3.3.8 Installation and Checkout

The Air Force has the option of extending the operation of the bioslurper system for up to 6 months at Wurtsmith AFB, if LNAPL recovery rates are promising. If extended testing is to be performed, additional site support will be required. The Air Force will need to provide electrical power for long-term operation of the bioslurper pump. Disposition of all generated wastes and routine operation and maintenance of the system will be the Air Force's responsibility. Battelle will provide technical support during the extended testing operation.

If the extended testing option is exercised, Battelle is scoped to remain on the site an additional 2 days after the short-term pilot test has been completed. The additional time on site will allow for connection of the bioslurper system to Air Force-supplied power. Battelle will provide the Base with a detailed operation manual for the bioslurper system and will provide operations training to Air Force personnel. The Base POC will be given a project record book to record system data. The POC will be given a Battelle contact and an alternative contact for technical assistance and will be contacted weekly for updates on system operation. At the end of the extended testing option (up to 6 months of operation), Battelle will return to the site to remove all bioslurper equipment. Disposal of all waste generated during the operation of the bioslurper system will be the responsibility of the Air Force.

4.0 BIOSLURPER SYSTEM DISCHARGE

4.1 Vapor Discharge Disposition

Battelle expects that the operation of the bioslurper test system at Wurtsmith AFB will not require a waiver or a point source air release registration. As per telephone conversation with Mr. Rich Alexander, the District #5 Supervisor for MDEQ/AQD, vapor reinjection is an acceptable alternative for vapor discharge disposition. This would result in entrained vapors, which according to the air sparging exclusion need not be abated. It is Battelle's intention to reinject off-gas vapors into soil in the contaminated zone by utilizing existing vent wells and monitoring wells if possible, which will resort in insignificant wuantities of TPH being released to the atmosphere. It can be assumed that the concentrations of TPH in reinjected vapors will be approximately 60 lb/day and benzene will be <1.0 lb/day. This value is based on the average discharge rates without treatment at three bioslurper test sites (Warner Robins AFB, Travis AFB, and Wright-Patterson AFB) that are contaminated with a type of fuel similar to that found at site SS-06; however, the discharge value may vary depending on concentrations in soil gas and the permeability of the soil. The data for benzene and TPH discharge levels for eight previous bioslurper sites are presented in Table 3.

To ensure regulatory compliance of the bioslurper system, surface emissions will be monitored using the dynamic surface emissions sampling methodology (Appendix C). Measurements will be taken prior to and following startup of the bioslurper to determine the effects of bioslurper operation on the vapors released to the atmosphere from the soil. Field soil gas screening instruments will be used to monitor concentration if the TPH in the reinjected vapors, and the volume of vapor discharge will be monitored daily using air flow instruments.

4.2 Aqueous Influent/Effluent Disposition

The flowrate of groundwater pumped by the bioslurper will be less than 10 gpm. TPH concentrations in the discharge water are expected to be less than 50 mg/L based on data from past bioslurper tests conducted at Wright-Patterson AFB, Warner Robins AFB, Travis AFB, McGuire AFB, and Dover AFB. These sites are contaminated with type of fuel similar to that found at the Wurtsmith AFB site. It may be necessary in Michigan to obtain a groundwater pumping waiver or registration permit. If one is required, the Base POC will inform Battelle of the necessary steps in

TABLE 3. BENZENE AND TPH VAPOR DISCHARGE LEVELS AT PREVIOUS BIOSLURPER TEST SITES

Site Location	Fuel Type	Extraction Rate (scfm)	Benzene (ppmv)	TPH (ppmv)	Benzene Discharge (lb/day)	TPH Discharge (lb/day)
Andrews AFB	No. 2 Fuel Oil	8.0	16	2,000	0.0010	0.20
Site 1, Bolling AFB	No. 2 Fuel Oil	4.0	0.20	153	0.00030	0.0090
Site 2, Bolling AFB	Gasoline	21	370	70,000	2.3	470
Johnston Atoll	JP-5 Jet Fuel	10	0.60	975	0.0017	5.7
Warner Robins AFB, UST 70/72	JP-4 Jet Fuel	5	515	37,000	0.74	110
Warner Robins AFB, SS010	JP-4 Jet Fuel	5.5	13	680	0.021	2.2
Travis AFB	JP-4 Jet Fuel	20	100	10,800	0.58	130
Wright-Patterson AFB	JP-4 Jet Fuel	3.0	ND	595	0	1.0

ND = Not detected.

TABLE 4. AIR RELEASE SUMMARY INFORMATION

Data Item	Air Release Information
Contractor Point of Contact	Jeff Kittel, (614) 424-6122
Contractor address	Battelle, 505 King Avenue, Columbus, OH 43201
Estimated total quantity of petroleum product to be recovered	To be determined
Description of petroleum product to be recovered	JP-4 jet fuel
Planned date of test start	To be determined
Test duration	9-10 days (active pumping)
Maximum expected volatile organic compound level in air	60 lb/day TPH, <1.0 lb/day benzene
Stack height above ground level	10 ft

obtaining the waiver or permit. The intention of Battelle staff will be to dispose of the wastewater by discharge directly to the Base sanitary sewer.

4.3 Free-Product Recovery Disposition

The bioslurper system will recover free-phase product from the pilot tests performed at Wurtsmith AFB. Recovered free product will be turned over to the Base for disposal and/or recycling. The volume of free product recovered from the Base will not be known until the tests have been performed. The maximum recovery rate for this system is 10 gpm, but the actual rate of LNAPL recovery likely will be much lower.

5.0 SCHEDULE

The schedule for the bioslurper fieldwork at Wurtsmith AFB will depend on approval of the project Test Plan. Battelle will determine a definitive schedule as soon as possible after approval is received. Battelle will have two to three staff members on site for approximately 2 weeks to conduct all necessary pilot testing. At the conclusion of the field testing at Wurtsmith AFB, all staff will return their Base passes. Battelle staff will remove all bioslurper field testing equipment from the Base before they leave the site, unless it is decided to exercise the extended testing option.

6.0 PROJECT SUPPORT ROLES

This section outlines some of the major functions of personnel from Battelle, Wurtsmith AFB, and AFCEE during the bioslurper field test.

6.1 Battelle Activities

The obligations of Battelle in the Bioslurper Initiative at Wurtsmith AFB will be to supply the staff and equipment necessary to perform all the tests on the bioslurper system. Battelle also will provide technical support in the areas of water and vapor discharge permitting, digging permits, staff support during the extended testing period, and any other technical areas that need to be addressed.

6.2 Wurtsmith AFB Support Activities

To support the necessary field tests at Wurtsmith AFB, the Base must be able to provide the following:

a. Any digging permits and utility clearances that need to be obtained prior to the initiation of the fieldwork. Any underground utilities should be clearly marked to reduce the chance of utility damage and/or personal injury during soil gas probe and possible well installation. Battelle will not begin field operations without these clearances and permits.

b. The Air Force will be responsible for obtaining Base and site clearance for the Battelle staff that will be working at the Base. The Base POC will be furnished with all necessary information on each staff member at least 1 week prior to field startup.

c. Access to the local sanitary sewer must be furnished so that Battelle staff can discharge the bioslurper aqueous effluent directly to the Base treatment facility.

d. Regulatory approval, if required, must be obtained by the Base POC prior to startup of the bioslurper pilot test. As stated previously, it is not likely that a waiver or permit to allow air releases or a point source air release registration will be required for emissions of approximately 60 lb/day of TPH and <1.0 lb/day benzene without treatment. A waiver for pumping and discharging groundwater at a rate of 10 gpm may be required. The Base POC will obtain all necessary Base permits prior to mobilization to the site. Battelle will provide technical assistance in preparing regulatory approval documents.

e. The Base also will be responsible for the disposition of all waste generated from the pilot testing. Such waste includes any soil cuttings generated from drilling, and all aqueous wastestreams produced from the bioslurper tests. All free product recovered from the bioslurper operation will be disposed of or recycled by the Base. Battelle will provide technical assistance in disposing of the waste generated from the bioslurper pilot test.

f. Before field activities begin, the Health and Safety Plan will be finalized with information provided by the Base POC. Table 5 is a checklist for the information required to complete the Health and Safety Plan. All emergency information will be obtained by the Site Health and Safety office before operations begin.

6.3 AFCEE Activities

The AFCEE POC will act as a liaison between Battelle and Wurtsmith AFB staff. The AFCEE POC will ensure that all necessary permits are obtained and the space required to house the bioslurper field equipment is found.

TABLE 5. HEALTH AND SAFETY INFORMATION CHECKLIST

Emergency Contacts	Name	Telephone Number
Hospital		
Fire Department	Emergency Switchboard	911/
Ambulance and Paramedics	Emergency Switchboard	911/
Police Department	Emergency Switchboard	911/
EPA Emergency Response Team	Switchboard	(800) 424-8802
Program Contacts		
Air Force	Patrick Haas	(210) 536-4314
Battelle	Jeff Kittel	(614) 424-6122
Wurtsmith AFB		
Other		
Emergency Routes		
Hospital ______		
Other ______		

7.0 REFERENCES

Battelle. 1995. *Test Plan and Technical Protocol for Bioslurping*. Prepared by Battelle Columbus Operations for the U.S. Air Force Center for Environmental Excellence, Brooks Air Force Base, Texas.

ICF Technology, Inc. 1994. The United Staes Air Force Installation Restoration Program. Second Draft RI/FS Work Plan. IRP Sites SS-06 and SS-13. Prepared for Wurtsmith Air Force Base, Oscoda, Michigan.

ICF Technology, Inc. 1996. The United States Air Force Installation Restoration Program Draft Feasibility Study Report, Site SS-06, ST-40, SS-12, and OT-46. Prepared for Wurtsmith Air Force Base, Oscoda, Michigan.

APPENDIX A

GEOLOGIC CROSS SECTION OF SITE SS-06, WURTSMITH AFB, MICHIGAN

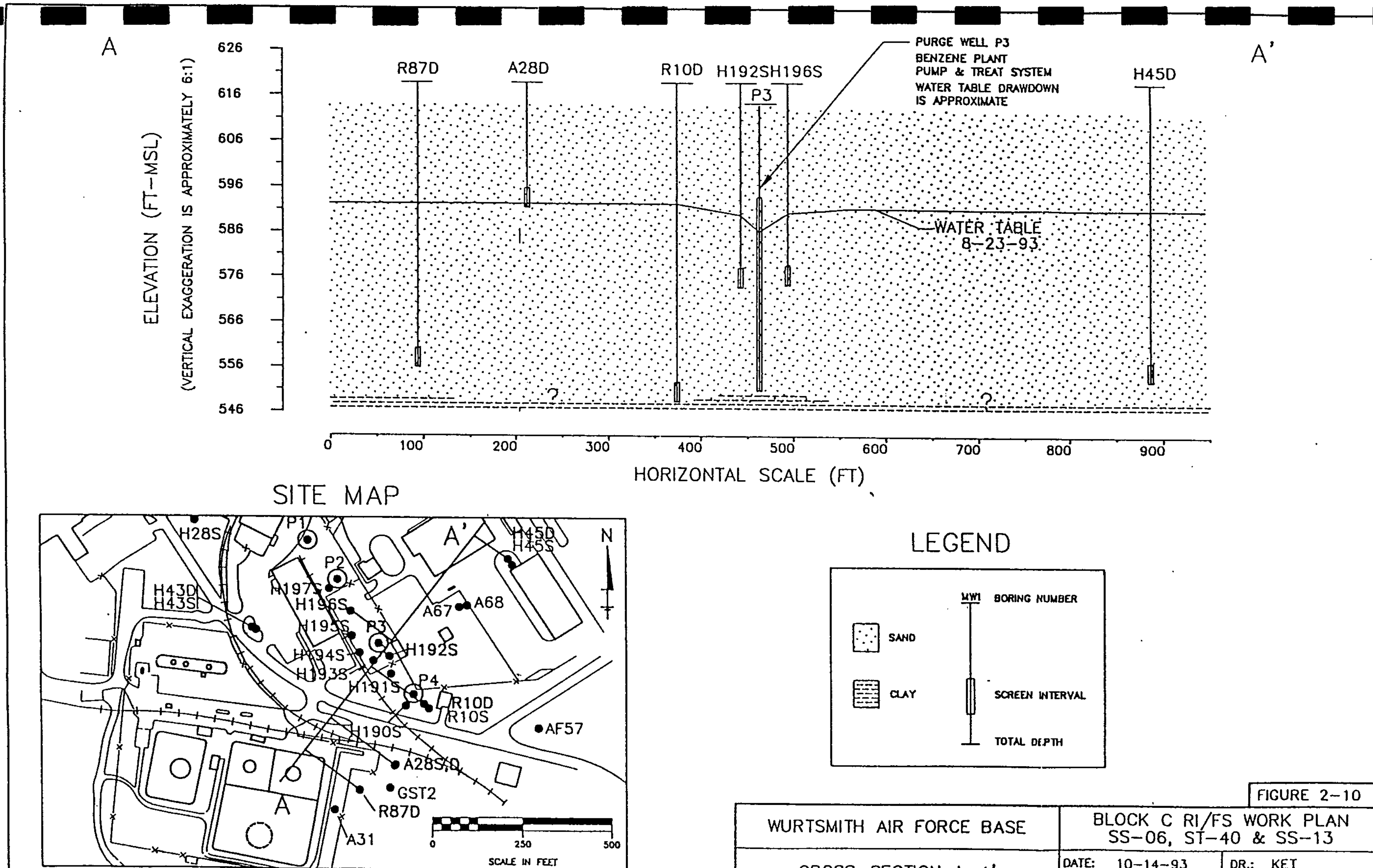

FIGURE 2-10

WURTSMITH AIR FORCE BASE	BLOCK C RI/FS WORK PLAN SS-06, ST-40 & SS-13	
CROSS-SECTION A-A'	DATE: 10-14-93	DR.: KET
	SCALE: AS SHOWN	DWG. NO. BLKCXS

APPENDIX B

WELL CONSTRUCTION SUMMARY AND WATER TABLE ELEVATIONS FOR EXISTING WELLS AT SS-06, WURTSMITH AFB, MICHIGAN

TABLE 2-2

WELL CONSTRUCTION SUMMARY AND WATER TABLE ELEVATIONS
FOR EXISTING WELLS IN BLOCK C IRP SITES
WURTSMITH AIR FORCE BASE, OSCODA, MI

WELL NO.	DATE INSTALLED	CASING DIA. (IN.)	WELL RISER ELEV. (FT-MSL)	SCREENED INTERVAL		TOTAL DEPTH OF BORING (FT-BGS)	WATER TABLE ELEV. (FT-MSL)	DATE MEASURED
				BOTTOM ELEV. (FT-MSL)	TOP ELEV. (FT-MSL)			
P1	10-89	8	NA	NA	NA	67	NA	NA
P2	10-89	8	NA	NA	NA	63	NA	NA
P3	10-89	8	NA	NA	NA	63	NA	NA
P4	10-89	8	NA	NA	NA	67	NA	NA
H190S	10-91	4	615.05	577.15	581.15	37.90	590.70	8-22-93
H191S	10-91	4	616.63	576.59	580.59	40.04	590.58	8-23-93
H192S	10-91	4	617.53	576.96	580.96	40.57	590.36	8-23-93
H193S	10-91	4	616.50	575.59	579.59	40.91	590.54	8-23-93
H194S	10-91	4	617.90	577.56	581.56	40.34	590.63	8-23-93
H195S	10-91	4	617.93	577.59	581.59	40.34	590.55	8-23-93
H196S	10-91	4	617.83	577.65	581.65	40.18	589.47	8-23-93
H197S	10-91	4	617.73	577.39	581.39	40.34	590.19	8-23-93
A28D	NA	2	NA	NA	NA	24.76	NA	8-23-93
GST2	4-84	6	NA	NA	NA	33.89	NA	8-23-93
R87D	NA	4	NA	NA	NA	57.23	NA	NA

Key: NA - Data Not Available.

41293-68-K

TABLE 2-2 (Continued)

WELL CONSTRUCTION SUMMARY AND WATER TABLE ELEVATIONS
FOR EXISTING WELLS IN BLOCK C IRP SITES
WURTSMITH AIR FORCE BASE, OSCODA, MI

WELL NO.	DATE INSTALLED	CASING DIA. (IN.)	WELL RISER ELEV. (FT-MSL)	SCREENED INTERVAL		TOTAL DEPTH OF BORING (FT-BGS)	WATER TABLE ELEV. (FT-MSL)	DATE MEASURED
				BOTTOM ELEV. (FT-MSL)	TOP ELEV. (FT-MSL)			
A31	NA	2	NA	NA	NA	23.21	NA	NA
A38	NA	2	NA	NA	NA	NA	NA	NA
R8S	NA	4	NA	NA	NA	30.41	NA	NA
R8D	NA	4	616.43	557.49	581.49	58.94	595.52	8-22-93
H28S	NA	4	618.71	579.43	583.43	39.28	591.86	8-23-93
H44S	NA	4	615.43	581.43	585.43	34.00	NA	NA
H44D	NA	4	615.52	555.52	559.52	60.00	NA	NA
H43S	NA	4	616.67	581.53	585.53	35.14	592.21	8-23-93
H43D	NA	4	616.68	554.61	558.61	62.07	592.17	8-23-93
R10S	NA	2	NA	NA	NA	NA	NA	NA
R10D	NA	4	615.39	552.81	556.81	62.58	591.31	8-23-93
AF75	NA	1.25	614.53	590.45	594.45	24.08	592.19	8-22-93
H47S	NA	4	614.19	578.99	582.99	35.20	592.14	8-22-93
R86S	NA	4	NA	NA	NA	NA	NA	8-22-93
R86D	NA	4	NA	NA	NA	62.02	NA	8-22-93
H45S	NA	4	614.25	580.25	584.25	34.00	NA	NA
H45D	NA	4	614.39	552.58	556.58	61.81	591.07	8-23-93

Key: NA - Data Not Available.

41293-68-K

Well #	Date	Time	Water Level	Product Level	Product Thickness	Comments
A35D	07/01/94	1100	24.35	23.62	0.73	Measured prior to bailing free product
A35D	07/01/94	1225	23.79	23.77	0.02	
A37D	07/01/94	1150	23.84	23.28	0.56	Measured prior to bailing free product
A37D	07/01/94	1425	23.79	23.28	0.51	
A40D	07/01/94	1202	23.81	23.26	0.55	Measured prior to bailing free product
A40D	07/01/94	1535	23.9	23.31	0.59	
A28D	07/01/94	1405	24.46	23.71	0.75	Measured prior to bailing free product
A28D	07/01/94	1540	24.39	23.8	0.59	
A41D	07/01/94	1435	23.95	23.31	0.64	Measured prior to bailing free product
A41D	07/01/94	1545	23.79	23.4	0.39	
A26D	07/01/94	1500	24.21	23.51	0.70	Measured prior to bailing free product
A26D	07/01/94	1550	23.75	23.65	0.10	
A11S	07/01/94	1510	23.65	23.62	0.03	Measured prior to bailing free product
A11D	07/01/94	1515	24.11	23.58	0.53	Measured prior to bailing free product
A11D	07/01/94	1640	23.87	23.58	0.29	
H196S	08/22/94	1456	28.56	28.24	0.32	Measured prior to bailing free product
H195S	08/22/94	1510	28.84	28.03	0.81	Measured prior to bailing free product
H194S	08/22/94	1516	28.68	27.85	0.83	Measured prior to bailing free product
H193S	08/22/94	1520	27.00	26.47	0.53	Measured prior to bailing free product
H192S	08/22/94	1524	28.91	27.66	1.25	Measured prior to bailing free product
H190S	08/22/94	1615	25.98	24.89	1.09	Measured prior to bailing free product
H191S	08/22/94	1620	27.64	26.56	1.08	Measured prior to bailing free product
A28D	08/23/94	810	23.68	23.42	0.26	
GST2	08/23/94	820	22.23	22.12	0.11	
R87D	08/23/94	830	23.19	23.17	0.02	
H191S	08/23/94	1345	27.65	26.57	1.08	
H192S	08/23/94	1420	28.82	27.60	1.22	
H193S	08/23/94	1420	27.22	26.58	0.64	
H195S	08/23/94	1445	28.61	28.19	0.42	
H194S	08/23/94	1530	28.49	27.99	0.50	
H196S	08/23/94	1515	28.71	28.44	0.27	
GST2	09/01/94	830	22.03	22.02	0.01	
A28D	09/01/94	830	23.38	23.38	0.00	
A40D	09/01/94	840	24.84	24.84	0.00	
A35D	09/01/94	840	25.00	25.00	0.00	
A37D	09/01/94	845	24.82	24.82	0.00	
A26D	09/01/94	855	23.36	23.08	0.28	
H196S	05/10/95	1810	29.80	28.10	1.70	
H195S	05/10/95	1820	28.97	28.11	0.86	
H194S	05/10/95	1830	28.89	27.97	0.92	
H193S	05/10/95	1840	28.02	26.51	1.51	

Well #	Date	Time	Water Level	Product Level	Product Thickness	Comments
H192S	05/10/95	1850	29.49	27.59	1.90	
A67	05/10/95	1855	26.40	25.23	1.17	
H190S	05/10/95	1750	26.09	24.90	1.19	
H191S	05/10/95	1755	28.46	26.48	1.98	
GST2	05/11/95	838	22.67	22.35	0.32	
H193S	04/08/95	1510	28.70	0.00	0.00	
H194S	04/08/95		27.12	0.00	0.00	
H195S	04/08/95		27.20	0.00	0.00	
H196S	04/08/95		27.18	0.00	0.00	
H191S	04/08/95		25.78	25.73	0.05	
H190S	04/08/95		24.04	0.00	0.00	
R10D	04/08/95		23.89	0.00	0.00	
AF74	04/08/95		27.49	0.00	0.00	
A67	04/08/95		24.07	24.06	0.01	
A68	04/08/95		24.06	0.00	0.00	
A28D	04/08/95		22.62	22.58	0.04	
GST2	04/08/95		23.37	23.32	0.05	
H190S	07/14/95				0.00	Bailer used to check for free product
H191S	07/14/95				0.00	Bailer used to check for free product
H192S	07/14/95				0.00	Bailer used to check for free product
H193S	07/14/95				0.00	Bailer used to check for free product
H194S	07/14/95				0.00	Bailer used to check for free product
H195S	07/14/95				0.00	Bailer used to check for free product
H196S	07/14/95				0.00	Bailer used to check for free product
GST2	07/14/95				0.00	Bailer used to check for free product
A28D	07/14/95				0.00	Bailer used to check for free product
A67	07/14/95				0.00	Bailer used to check for free product
A68	07/14/95				0.00	Bailer used to check for free product
A67	11/06/95				0.00	Bailer used to check for free product
A68	11/06/95				0.00	Bailer used to check for free product
H192S	11/06/95				0.00	Bailer used to check for free product
H196S	11/28/95				0.00	Bailer used to check for free product
H195S	11/28/95				0.00	Bailer used to check for free product
H194S	11/28/95				0.00	Bailer used to check for free product
H193S	11/28/95				0.01	Bailer used to check for free product
H191S	11/28/95				0.10	Bailer used to check for free product
H190S	07/09/96		24.82	0.00	0.00	
H191S	07/09/96		26.54	26.40	0.14	
H192S	07/09/96		28.44	27.32	1.12	
H193S	07/09/96		26.40	26.38	0.02	
H194S	07/09/96		27.76	27.73	0.03	

Well #	Date	Time	Water Level	Product Level	Product Thickness	Comments
H195S	07/09/96		27.95	27.88	0.07	
H196S	07/09/96		28.33	28.02	0.31	
HGST2	07/09/96		27.71	0.00	0.00	

APPENDIX C

DESCRIPTION OF SURFACE EMISSIONS TESTING

5.7 Dynamic Surface Emissions Sampling Method

An area of soil is enclosed under an inert box designed to allow the purging of the enclosure with high-purity air. The purging activity removes ambient air from the region above the soil and allows an equilibrium to be established between hydrocarbons emitted from the soil and the organic-free air. The airstream is then sampled by drawing a known volume of the hydrocarbon/pure air mixture through a tube packed with sorbent materials. The sorbents retain any organics associated with the soil surface. The sample tube is thermally desorbed, and the organics are resolved and quantified by gas chromatography. These measured concentrations are then applied to a formula that makes it possible to calculate the hydrocarbon emission rates from the soil to the atmosphere.

5.7.1 Sampling System

The sampling system used for surface emission sampling is shown in Figure 22. The system consists of a square Teflon™ box that covers a surface area of 0.453 m^2. The box is fitted with inlet and outlet ports for the entry and exit of the high-purity air. Inside the box is a manifold that delivers the air supply uniformly across the soil surface. The same type of manifold is fitted to the exit port of the box. This configuration delivers an even flow of air across the entire soil surface under the box so that a representative sample is being generated. The air exiting the Teflon™ box is exhausted through Teflon™ tubing and is available for sampling.

In all cases, a totally inert system is employed. Teflon™ tubing and stainless steel fittings assure that there is no contribution to or removal of organics from the airstream. A personal monitoring pump (SKC Model #224-PCXR7) is located on the back side of the sorbent tube, which is connected to the exhaust line for sampling.

5.7.2 Sorbent Sampling Tubes

The compounds of interest during surface emissions testing are branched and straight-chained hydrocarbons, and aromatics. A total petroleum hydrocarbon (TPH) value also is monitored. To

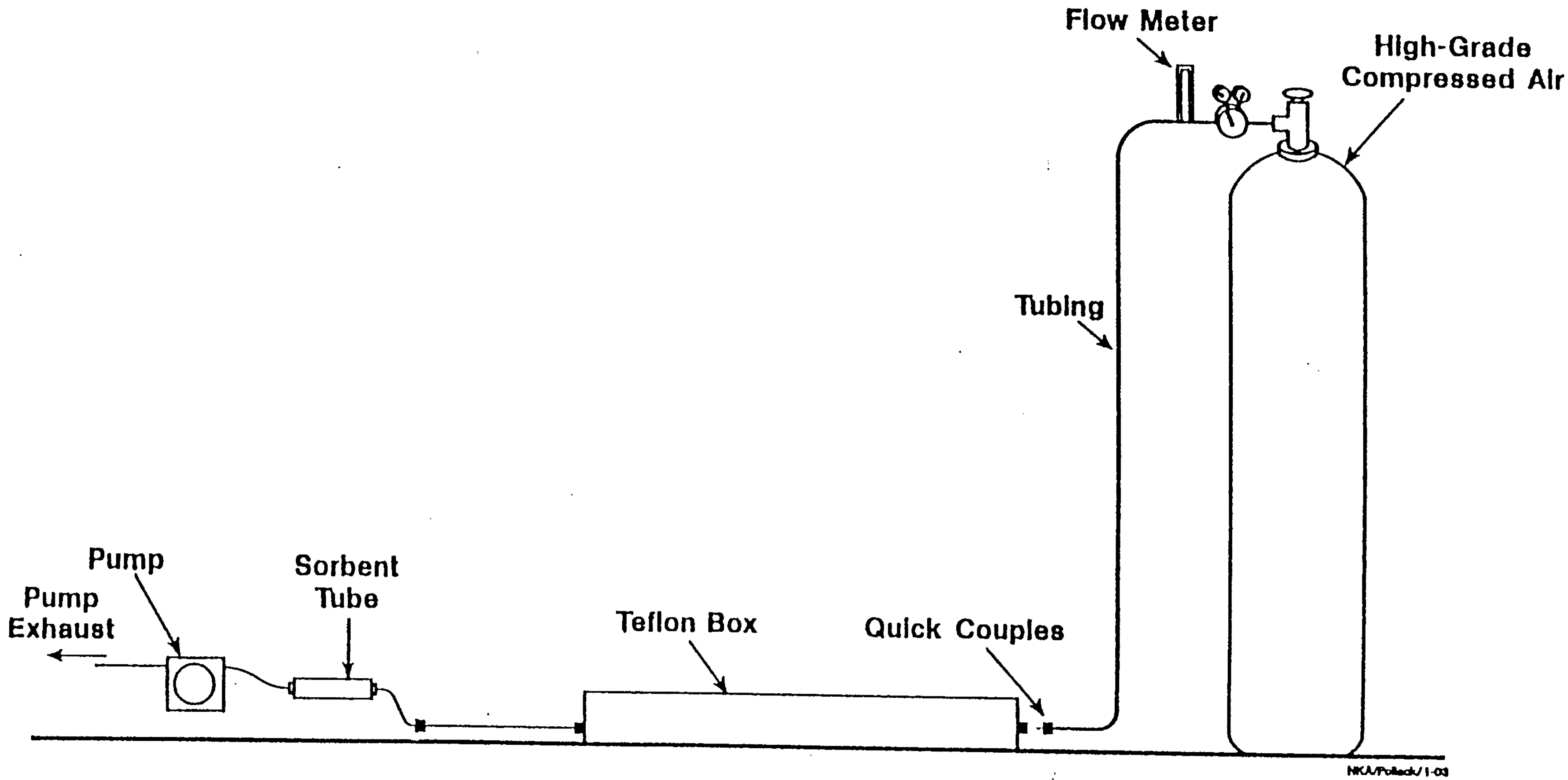

Figure 22. Surface Emissions Sampling Components

capture these compounds efficiently, a three-stage carbon-based sorbent bed (Supelco, Carbotrap 300 Cat.#2-0370) is employed (Figure 23). This configuration has been examined extensively at Battelle (Pollack and Gordon, 1993) in conjunction with ambient air sampling and has been shown to be very efficient at capturing and retaining a wide range of VOCs. This carbon-based sorbent bed typically displays very low background artifact levels.

The air samples are pulled through the tube in a direction such that the air passes from the weakest sorbent (Carbotrap C) to the moderately strong material (Carbotrap) and finally onto the strongest sorbent (Carbosieve S-III). This three-phased arrangement makes it possible to capture a wide range of molecular-weight VOCs while still allowing efficient desorption. Tube desorbing is done by backflushing the organics off the sorbent bed while heating the tube.

Prior to using a sampling tube, the tube is baked out at 350°C for a period of 1 hour with a helium purge flow of 50 cc/minute. This process assures that the sorbents are clean and ready for use.

5.7.3 Field Sampling Technique

The collection of surface emission samples involves the following activities:

1. Assure that the sorbent tubes have been conditioned prior to their use in the sampling program.

2. Set the flow of the SKC pump to ~50 cc/minute using a Mini-Buck gas flow calibrator (Model #APB-M5). Install a spare sorbent tube in line such that air is being pulled through it by the pump in the sampling direction identified on the tube. Connect the Mini-Buck calibrator to the inlet end of the sorbent tube and adjust the flowrate of the pump so that the airflow through the tube is 50 cc/minute. Remove the sorbent tube and measure the pump flow once again. This is the flowrate necessary to pull a 50-cc/minute rate through the packed tube (in the range of ~60 cc/minute). This flow setting tube is not used for sampling.

3. Install the regulator and flowmeter on the high-grade air cylinder and set a flowrate of 2 L/minute, once again using the Mini-Buck calibrator. The cylinder delivery pressure should be set to ~60 psig prior to adjusting the flow.

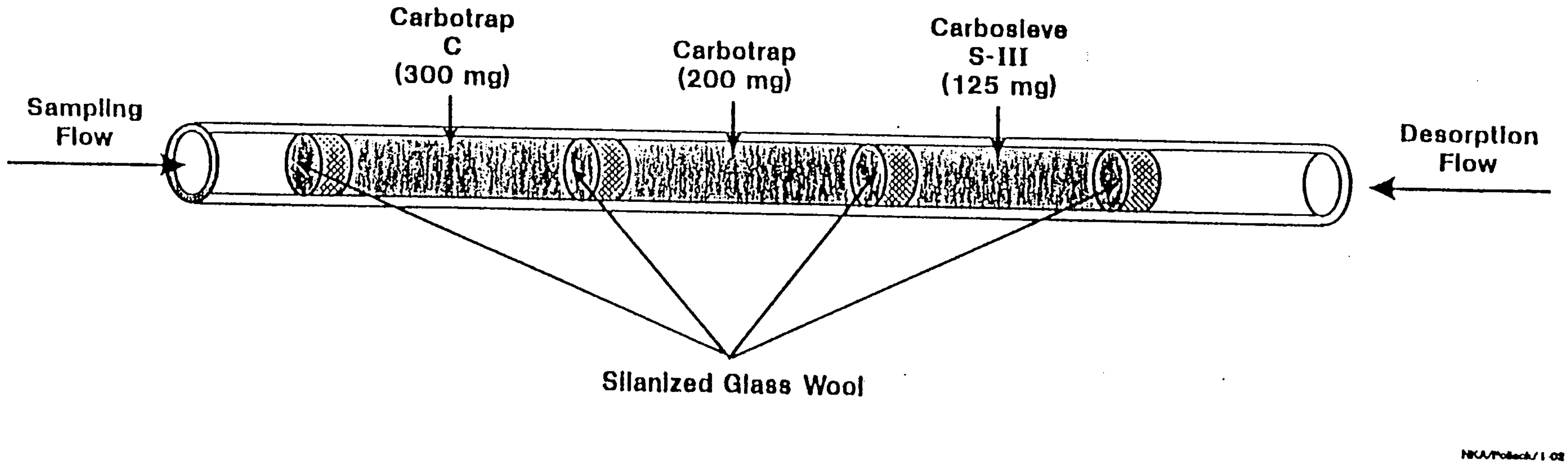

Figure 23. Sorbent Sampling Tube

4. Check all of the tubing and fittings on the Teflon™ box. Repair or replace as necessary.

5. Position the Teflon™ box soil enclosure unit at the location where the sampling is to be done. It may be necessary to loosen the soil around the perimeter of the box to allow it to be in continuous contact with the soil. In all cases, the surface of the soil is disturbed as little as possible and any soil observations at the site are recorded.

6. The inlet tubing on the Teflon™ box is connected to the air cylinder and the exhaust tubing is checked to confirm that there is no restriction of flow. The 2-hour purge is then started, to obtain equilibrium between surface emissions and the high-grade air.

7. At the end of the 2-hour purge time, a clean sorbent tube is connected to the sample line with the SKC pump connected to the back side of the tube. The pump is started and run for a timed period of 10 minutes. This results in a 500-cc volume of air being passed through the sorbent sampling tube.

8. The sorbent tube is removed from the sampling train and returned to its storage tube. The sample tube number, sampling location, date, time, and any observations are recorded in the notebook.

9. The Teflon™ box is then repositioned at the next location, and the purge/sampling procedure is repeated.

10. In addition to the individual site samples, duplicate samples, blanks from the high-grade air cylinder, ambient air samples, and "trip blanks," where no sample is loaded onto a conditioned tube, may be collected. These extra samples are used as quality control samples.

5.8 Technique for Processing the Sorbent Sampling Tubes from Surface Emissions Sampling

The organic compounds retained by the sorbent materials in the sampling tubes are thermally desorbed, refocused, and analytically resolved via gas chromatography. A calibration mixture that contains the compounds of interest also is processed to establish retention times for these compounds. Quantitation may be based on the response factors for specific compounds or calculated by applying a hexane response factor with correction for the number of carbons actually present in each compound.

5.8.1 Instrumentation

The instrumentation and analytical technique used to process the sorbent tubes is based on U.S. EPA Method TO-14 that is employed to identify toxic organics in ambient air (EPA, 1988). This method involves (1) the collecting of VOCs in a gas sample on a cryogenically cooled glass bead trap; (2) the transfer of the trapped organics by ballistically heating the cold trap; and (3) the delivery of the organics to a gas chromatograph for qualitative/quantitative analysis. The modification to the method when using sorbent tubes is the extra step of heating the tube to deliver the remotely collected organics to the cold glass bead trap.

The automated gas chromatograph (GC) system (Figure 24) consists of a Hewlett-Packard Model 5890 GC with a flame ionization detector (FID). A Hewlett-Packard 3396A integrator in conjunction with a 9122 disk drive receives detector output signals and stores data. The disk drive also provides access to the program used to automate processing. A modified NuTech Model 320 sample preconcentration unit is used to collect the organics from the tube. The unit contains two subsystems: (1) an electronic console that regulates various temperature zones, and (2) the sample-handling subassembly containing a 6-port valve and trap. The console controls the temperatures of the valve body (120°C), sample transfer lines (120°C), and the refocusing trap. The trap temperature is regulated by the controlled release of liquid nitrogen via a solenoid valve. The trap temperature during sample transfer from the sorbent tube is maintained at -150°C. The trap is heated to 130°C for delivery of organics to the GC.

Sample flow from the sorbent tube to the refocusing trap is controlled using: (1) a Tylan™ readout control unit, Model R032-b; (2) a Tylan™ zero to 100 standard cm^3/min mass flow controller, Model MFC-260; (3) a Thomas™ dual diaphragm pump; and (4) a Perma Pure Dryer, Model MD-125-48F. The readout control unit, in conjunction with the mass flow controller, regulates the sample transfer flow rate from the sorbent tube to the trap. The Perma Pure Dryer with a tubular hygroscopic ion-exchange membrane (Nafion) is used to selectively remove any water vapor from the sorbent sample. The Nafion™ tube size is 30 cm × 0.1 cm ID, embedded within a shell of Teflon™ tubing of 0.25 cm ID. A countercurrent flow of dry zero air (300 cc) is used to purge the shell. This type of dryer has been shown to have no affinity for the BTEX compounds or straight-

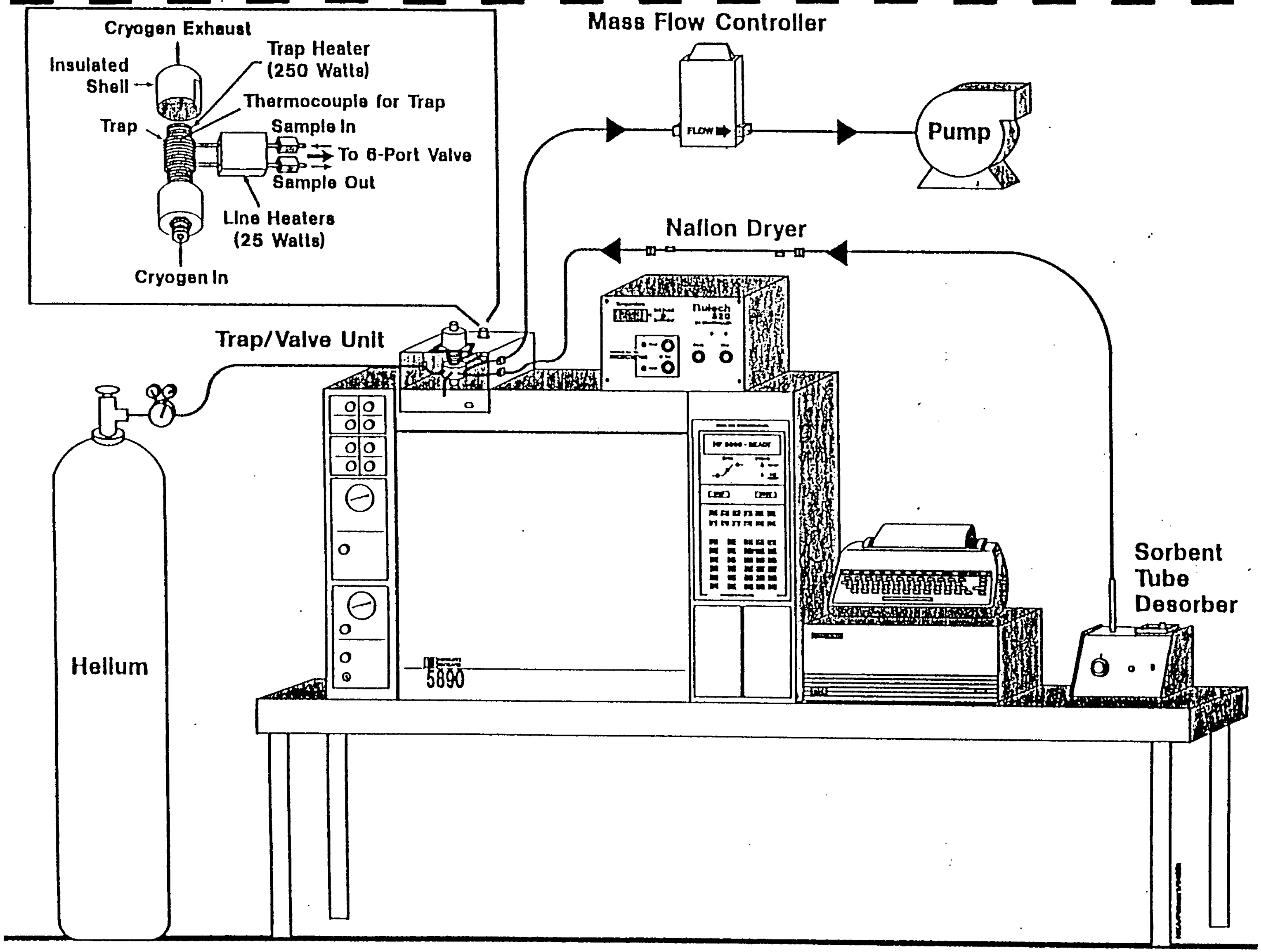

Figure 24. Automated Gas Chromatograph

chained/branched petroleum hydrocarbons (Pliel et al., 1987).

A Dynatherm™ Model 10 sorbent tube conditioner/desorber is used to heat the sorbent tube to deliver the organics to the analytical system. A desorption temperature of 250°C with a helium purge gas flow of 20 cc/min is used during the desorption process. The desorption time for a tube is set at 15 minutes, resulting in a total helium backflush volume of 300 cc.

Separations chemistry is accomplished using two 30-m HP-1 series capillary columns joined with a zero dead-volume butt connector. The internal diameter of the capillary is 0.53 mm with a 2.65 μm film thickness. The optimal chromatographic resolution is obtained by temperature programming the GC oven from -50°C to 200°C at a rate of 8 degrees per minute. An FID chromatogram of 19 compounds that are typically associated with JP-4 fuel is presented in Figure 25.

5.8.2 Calculation of Surface Emissions Flux Rates

To calculate the actual emission rates of organic compounds from the soil surface into the atmosphere, the following formula for dynamic enclosure techniques is employed (McVeety, 1993):

$$F = CVr/S$$

where

F = flux in mass/area-time
C = the concentration of the gas in units of mass/volume
Vr = volumetric flowrate of sweep gas
S = soil surface covered by enclosure (McVeety, 1993).

Sample Calculation:

Benzene concentration = 6.88 ppbv at a sampling site.
To generate the "C" value of mass/volume:
6.88 ppbv = 0.00688 ppmv
1 ppmv of benzene, with a molecular weight of 78, is = 0.00319 mg/L. Therefore, 0.00688 ppmv = 0.00688 $\times$ 0.00319 mg/L = 0.0000219 mg/L. "C" = 0.0000219 mg/L.

Vr = Volumetric flowrate of the sweep gas or 2 L/min.

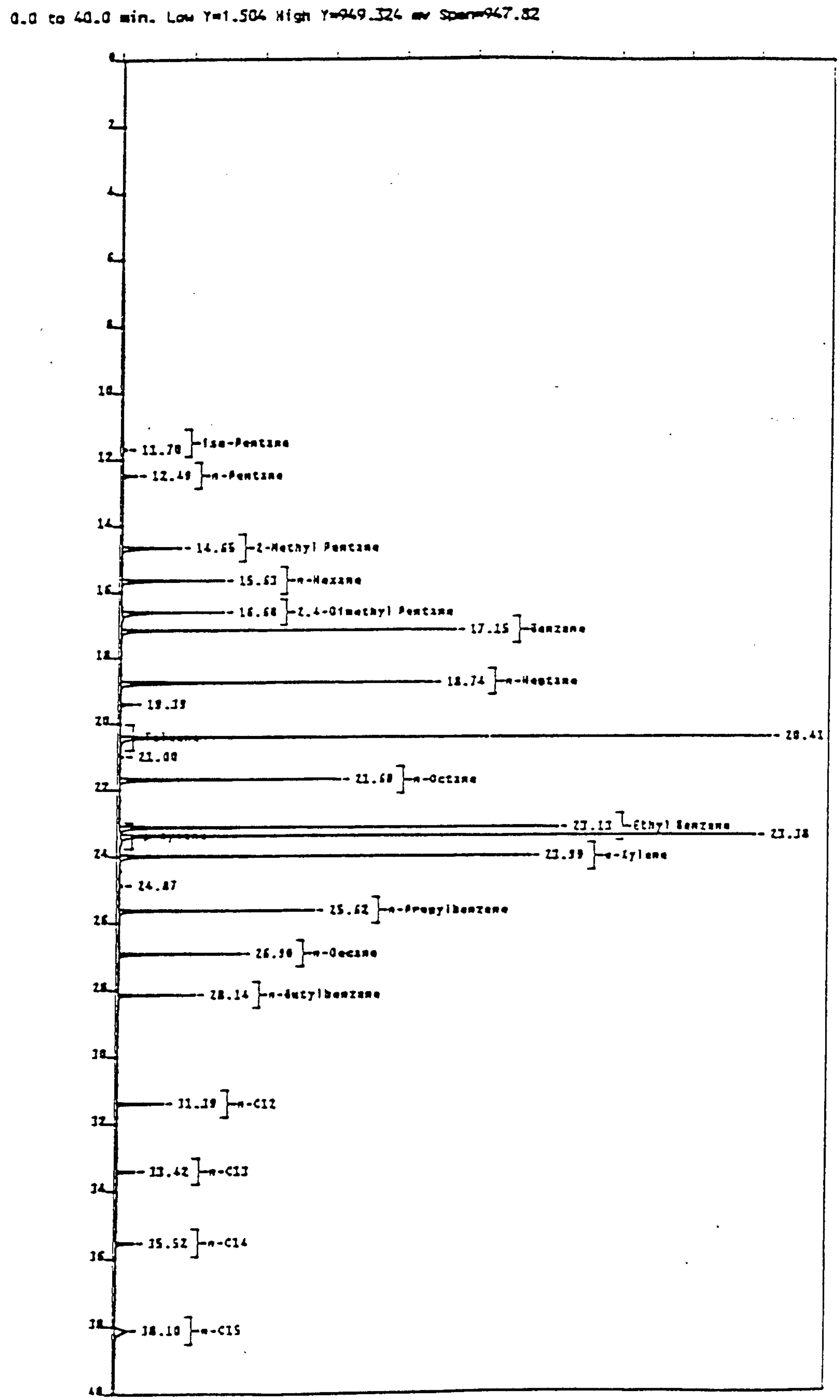

Figure 25. FID Chromatogram of 19 Compounds Typically Associated with JP-4 Jet Fuel

S = Soil surface covered by the box is a constant 0.453 m^2.

Therefore:

$$F = (0.0000219 \text{ mg/L} \times 2 \text{ L/min})/0.453\text{m}^2,$$

$$F = 0.00004380 \text{ mg benzene}/0.453 \text{ m}^2/\text{min},$$

or

$$F = 0.04380 \ \mu\text{g benzene}/0.453 \text{ m}^2/\text{min}.$$

APPENDIX B

LABORATORY ANALYTICAL REPORTS

@ AIR TOXICS LTD.

AN ENVIRONMENTAL ANALYTICAL LABORATORY

WORK ORDER #: 9608080

Work Order Summary

CLIENT: Ms. Amanda Bush
Battelle Memorial Institute
505 King Avenue
Columbus, OH 43201-2693

BILL TO: Same

PHONE: 614-424-4996
FAX: 614-424-3667
DATE RECEIVED: 8/7/96
DATE COMPLETED: 8/15/96

INVOICE # 11279
P.O. # 91221
PROJECT # G462201-30B2101 WURTSMITH
AMOUNT$: $439.16

FRACTION #	NAME	TEST	RECEIPT VAC./PRES.	PRICE
01A	WUR-RE-INJECT-1	TO-3	0.5 "Hg	$120.00
02A	WUR-RE-INJECT-2	TO-3	0 "Hg	$120.00
02AA	WUR-RE-INJECT-2 Duplicate	TO-3	0 "Hg	NC
03A	WUR-RE-INJECT-3	TO-3	1.0 "Hg	$120.00
04A	Method Spike	TO-3	NA	NC
05A	Lab Blank	TO-3	NA	NC

Misc. Charges	1 Liter Summa Canister Preparation (3) @ $15.00 each.	$45.00
	Shipping (7/30/96)	$34.16

CERTIFIED BY: *[signature]*
Laboratory Director

DATE: 8/15/96

AIR TOXICS LTD.

SAMPLE NAME: WUR-RE-INJECT-1

ID#: 9608080-01A

EPA METHOD TO-3

(Aromatic Volatile Organics in Air)

GC/PID

File Name:	**6080916**		**Date of Collection: 8/2/96**	
Dil. Factor:	**205**		**Date of Analysis: 8/9/96**	
Compound	**Det. Limit (ppmv)**	**Det. Limit (uG/L)**	**Amount (ppmv)**	**Amount (uG/L)**
Benzene	0.21	0.67	12	39
Toluene	0.21	0.79	40	150
Ethyl Benzene	0.21	0.90	7.9	35
Total Xylenes	0.21	0.90	26	110

TOTAL PETROLEUM HYDROCARBONS

GC/FID

(Quantitated as Jet Fuel)

File Name:	**6080916**		**Date of Collection: 8/2/96**	
Dil. Factor:	**205**		**Date of Analysis: 8/9/96**	
Compound	**Det. Limit (ppmv)**	**Det. Limit (uG/L)**	**Amount (ppmv)**	**Amount (uG/L)**
TPH* (C5+ Hydrocarbons)	2.1	14	5600	36000
C2 - C4** Hydrocarbons	2.1	3.8	73	130

*TPH referenced to Jet Fuel (MW=156)

**C2 - C4 Hydrocarbons referenced to Propane (MW=44)

Container Type: 1 Liter Summa Canister

AIR TOXICS LTD.

SAMPLE NAME: WUR-RE-INJECT-2

ID#: 9608080-02A

EPA METHOD TO-3

(Aromatic Volatile Organics in Air)

GC/PID

File Name:	**6080917**		**Date of Collection:**	**8/2/96**
Dil. Factor:	**101**		**Date of Analysis:**	**8/9/96**
Compound	**Det. Limit (ppmv)**	**Det. Limit (uG/L)**	**Amount (ppmv)**	**Amount (uG/L)**
Benzene	0.10	0.33	9.3 M	30 M
Toluene	0.10	0.39	18	69
Ethyl Benzene	0.10	0.45	5.0	22
Total Xylenes	0.10	0.45	17	75

TOTAL PETROLEUM HYDROCARBONS

GC/FID

(Quantitated as Jet Fuel)

File Name:	**6080917**		**Date of Collection:**	**8/2/96**
Dil. Factor:	**101**		**Date of Analysis:**	**8/9/96**
Compound	**Det. Limit (ppmv)**	**Det. Limit (uG/L)**	**Amount (ppmv)**	**Amount (uG/L)**
TPH* (C5+ Hydrocarbons)	1.0	6.5	3600	23000
C2 - C4** Hydrocarbons	1.0	1.8	44	80

*TPH referenced to Jet Fuel (MW=156)

**C2 - C4 Hydrocarbons referenced to Propane (MW=44)

M = Reported value may be biased due to apparent matrix interferences.

Container Type: 1 Liter Summa Canister

AIR TOXICS LTD.

SAMPLE NAME: WUR-RE-INJECT-2 Duplicate

ID#: 9608080-02AA

EPA METHOD TO-3

(Aromatic Volatile Organics in Air)

GC/PID

File Name:	**6080918**		**Date of Collection: 8/2/96**	
Dil. Factor:	**101**		**Date of Analysis: 8/9/96**	
Compound	**Det. Limit (ppmv)**	**Det. Limit (uG/L)**	**Amount (ppmv)**	**Amount (uG/L)**
Benzene	0.10	0.33	9.5 M	31 M
Toluene	0.10	0.39	18	69
Ethyl Benzene	0.10	0.45	5.1	22
Total Xylenes	0.10	0.45	17	75

TOTAL PETROLEUM HYDROCARBONS

GC/FID

(Quantitated as Jet Fuel)

File Name:	**6080918**		**Date of Collection: 8/2/96**	
Dil. Factor:	**101**		**Date of Analysis: 8/9/96**	
Compound	**Det. Limit (ppmv)**	**Det. Limit (uG/L)**	**Amount (ppmv)**	**Amount (uG/L)**
TPH* (C5+ Hydrocarbons)	1.0	6.5	3600	23000
C2 - C4** Hydrocarbons	1.0	1.8	41	75

*TPH referenced to Jet Fuel (MW=156)

**C2 - C4 Hydrocarbons referenced to Propane (MW=44)

M = Reported value may be biased due to apparent matrix interferences.

Container Type: 1 Liter Summa Canister

AIR TOXICS LTD.

SAMPLE NAME: WUR-RE-INJECT-3

ID#: 9608080-03A

EPA METHOD TO-3

(Aromatic Volatile Organics in Air)

GC/PID

File Name:	**6080919**		**Date of Collection: 8/6/96**	
Dil. Factor:	**17.4**		**Date of Analysis: 8/9/96**	
Compound	**Det. Limit (ppmv)**	**Det. Limit (uG/L)**	**Amount (ppmv)**	**Amount (uG/L)**
Benzene	0.017	0.057	1.2	3.9
Toluene	0.017	0.067	2.9	11
Ethyl Benzene	0.017	0.077	0.60	2.6
Total Xylenes	0.017	0.077	2.8	12

TOTAL PETROLEUM HYDROCARBONS

GC/FID

(Quantitated as Jet Fuel)

File Name:	**6080919**		**Date of Collection: 8/6/96**	
Dil. Factor:	**17.4**		**Date of Analysis: 8/9/96**	
Compound	**Det. Limit (ppmv)**	**Det. Limit (uG/L)**	**Amount (ppmv)**	**Amount (uG/L)**
TPH* (C5+ Hydrocarbons)	0.17	1.1	540	3500
C2 - C4** Hydrocarbons	0.17	0.32	0.60	1.1

*TPH referenced to Jet Fuel (MW=156)

**C2 - C4 Hydrocarbons referenced to Propane (MW=44)

Container Type: 1 Liter Summa Canister

AIR TOXICS LTD.

SAMPLE NAME: Method Spike
ID#: 9608080-04A

EPA METHOD TO-3
(Aromatic Volatile Organics in Air)

GC/PID

File Name:	**6080901**	**Date of Collection: NA**	
Dil. Factor:	**1.00**	**Date of Analysis: 8/9/96**	

Compound	Det. Limit (ppmv)	Det. Limit (uG/L)	% Recovery
Benzene	0.001	0.003	108
Toluene	0.001	0.004	106
Ethyl Benzene	0.001	0.004	89
Total Xylenes	0.001	0.004	92

TOTAL PETROLEUM HYDROCARBONS
GC/FID
(Quantitated as Jet Fuel)

File Name:	**6080901**	**Date of Collection: NA**	
Dil. Factor:	**1.00**	**Date of Analysis: 8/9/96**	

Compound	Det. Limit (ppmv)	Det. Limit (uG/L)	% Recovery
TPH* (C5+ Hydrocarbons)	0.010	0.065	83
C2 - C4** Hydrocarbons	0.010	0.018	83

*TPH referenced to Jet Fuel (MW=156)
**C2 - C4 Hydrocarbons referenced to Propane (MW=44)

Container Type: NA

AIR TOXICS LTD.

SAMPLE NAME: Lab Blank
ID#: 9608080-05A

EPA METHOD TO-3
(Aromatic Volatile Organics in Air)

GC/PID

File Name:	6080908		Date of Collection: NA	
Dil. Factor:	1.00		Date of Analysis: 8/9/96	

Compound	Det. Limit (ppmv)	Det. Limit (uG/L)	Amount (ppmv)	Amount (uG/L)
Benzene	0.001	0.003	Not Detected	Not Detected
Toluene	0.001	0.004	Not Detected	Not Detected
Ethyl Benzene	0.001	0.004	Not Detected	Not Detected
Total Xylenes	0.001	0.004	Not Detected	Not Detected

TOTAL PETROLEUM HYDROCARBONS
GC/FID
(Quantitated as Jet Fuel)

File Name:	6080908		Date of Collection: NA	
Dil. Factor:	1.00		Date of Analysis: 8/9/96	

Compound	Det. Limit (ppmv)	Det. Limit (uG/L)	Amount (ppmv)	Amount (uG/L)
TPH* (C5+ Hydrocarbons)	0.010	0.065	Not Detected	Not Detected
C2 - C4** Hydrocarbons	0.010	0.018	Not Detected	Not Detected

*TPH referenced to Jet Fuel (MW=156)
**C2 - C4 Hydrocarbons referenced to Propane (MW=44)

Container Type: NA

AIR TOXICS LTD.
AN ENVIRONMENTAL ANALYTICAL LABORATORY

180 BLUE RAVINE ROAD, SUITE B
FOLSOM, CA 95630-4719
(916) 985-1000 FAX: (916) 985-1020

CHAIN-OF-CUSTODY RECORD

№ 007977
Page 1 of 1

Contact Person MATT PLACE
Company BATTELLE
Address 505 KING AVE. City COLUMBUS State OH Zip 43201
Phone 614-424- FAX 614-424-3667

Collected By: Signature

Project info:
P.O. #
Project # G462201-30B2101
Project Name WURTSMITH

Turn Around Time:
☑ Normal
☐ Rush ______ Specify

Lab I.D.	Field Sample I.D.	Date & Time	Analyses Requested	Canister Pressure / Vacuum Initial	Final	Receipt
01A	WUR-~~SOIL/GAS/AIR-1~~ RE-INJECT-1	08/02/96 4:00pm	BTEX + TPH	28" Hg	0	0.5" Hg
02A/AA	WUR-RE-INJECT-2	08/02/96 7:15pm	BTEX + TPH	27.5" Hg	0	0" Hg
03A	WUR-RE-INJECT-3	08/06/96 10:40am	BTEX + TPH	28" Hg	0	1.0" Hg
						8/8/96

Relinquished By: (Signature) Date/Time — Shane S. Walton 08/06/96 1:00pm — Print Name: SHANE WALTON
Relinquished By: (Signature) Date/Time — Kip Hewahea 8/6/96 11:30AM — Received By: (Signature) Date/Time
Relinquished By: (Signature) Date/Time — Received By: (Signature) Date/Time — Scott Amerson ATL 8/7/96 1132

Notes:

Lab Use Only	Shipper Name	Air Bill #	Opened By:	Date/Time	Temp. (°C)	Condition	Custody Seals Intact?	Work Order #
	FEDEX	9612390432	[illegible]	8/7/96 1132	AMBIENT	GOOD	Yes No None N/A	9608080

Form 1293 rev. 06

Battelle
Columbus Laboratories

CHAIN OF CUSTODY RECORD

Form No. ______

Proj. No. G462201-30B2101

Project Title WURTSMITH PILOT STUDY / INSTALLATION + CHECKOUT

SAMPLERS: (Signature) Shane S. Walton

DATE	TIME	SAMPLE I.D.	BTEX	BULK DENSITY	MOISTURE CONTENT	PARTICLE SIZE DISTRIBUTION	POROSITY	TPH	Container No.	Number of Containers	Remarks
07/31/96	3:00pm	WUR-SS-1	X	X	X	X	X	X		1	
07/31/96	3:10pm	WUR-SS-1	X	X	X	X	X	X		1	
08/02/96	12:00pm	WUR-H2O-1	X					X		1	TPH AS PURGABLE
08/04/96	7:40 pm	WUR-H2O-2	X					X		1	TPH AS PURGABLE
08/04/96	7:40 PM	WUR-H2O-3	X					X		1	TPH AS PURGABLE
08/06/96	11:00 AM	WUR-H2O-4	X					X		1	TPH AS PURGABLE
08/06/96	11:00 AM	WUR-H2O-5	X					X		1	TPH AS PURGABLE

Relinquished by: (Signature)	Date/Time	Received by: (Signature)	Relinquished by: (Signature)	Date/Time	Received by: (Signature)
Shane S. Walton	08/06/96 1:30AM				
Relinquished by: (Signature)	Date/Time	Received by: (Signature)	Relinquished by: (Signature)	Date/Time	Received by: (Signature)
Relinquished by: (Signature)	Date/Time	Received for Laboratory by: (Signature)	Date/Time	Remarks	
		[illegible signature]	8/7/96 0930		

Alpha Analytical, Inc.
255 Glendale Avenue, Suite 21
Sparks, Nevada 89431
Phone (702) 355-1044
Fax (702) 355-0406

Page # 1 of 1

Billing Information:
Name
Address
City, State, Zip
Phone Number ? Fax

Client Name Battelle	P.O.#	Job # 0462201-30B10	
Address	PWS #	DWR #	
City, State, Zip	Phone #	Fax #	
Office Use Only / Sampled by Client	Report Attention Shane		

Time Sampled	Date Sampled	Matrix* See Key Below	Lab ID Number	Sample Description	Total and type of containers ** See below	BTXE	TPH	TPHgas	Bulk Density	Moisture Content	Particle Size	Porosity					
	7/31	SO	BMI080796-01	WUR-SS-1	1B	X	X	X	X	X	X	X					
	✓	✓	02	WUR-SS-2	1B	X	X		X	X	X	X					
	8/2	AQ	03	WUR-H2O-1	1V			X									
	8/4		04	" " 2	1V			X									
	✓		05	" " 3	1V			X									
	8/6		06	" " 4	1V			X									
	8/6		07	" " 5	1V			X									

REMARKS:
WUR-SS-2 it says 1 on the COC but 2 on the BRASS Tube.

	Signature	Print Name	Company	Date	Time
Relinquished by					
Received by	[signature]	Linda Bydairk	AAI	8/7/96	1030
Relinquished by	[signature]	Craig Giecy	AAI	8/4/96	1500
Received by	[signature]	[signature]	[illegible]	8/7/96	1500
Relinquished by					
Received by					

NOTE: Samples are discarded 60 days after results are reported unless other arrangements are made. Hazardous samples will be returned to client or disposed of at client expense.

[redacted] AQ [redacted] SO [redacted] Waste [redacted] OT [redacted] : L [redacted] V [redacted] S [redacted] T [redacted] B-Brass [redacted] P-Plastic [redacted] OT-Other [redacted]

Laboratory Analysis Report

Sierra Environmental Monitoring, Inc.

ALPHA ANALYTICAL
255 GLENDALE AVENUE, SUITE 21
SPARKS NV 89431

Date : 8/12/96
Client : ALP-855
Taken by: CLIENT
Report : 17089
PO# :

Sample	Collected Date	Time	MOISTURE CONTENT %	DENSITY G/CM3	POROSITY %	PARTICLE SIZE DISTIBUTION FRACTION %		
3MI080796-01 - WUR-SS-1	7/31/96	:	5.07	1.21	54.3	SEE REPORT		
3MI080796-02 - WUR-SS-2	7/31/96	:	4.06	1.20	54.8	SEE REPORT		

proved By:

is report is applicable only to the sample received by the laboratory. The liability of the laboratory is limited to the amount paid for this report. This report is for the exclusive use of the client to whom it is addressed and upon the condition that the client assumes all liability for the further distribution of the report or its contents.

1135 Financial Blvd.
Reno, NV 89502
Phone (702) 857-2400
FAX (702) 857-2404

illiam F. Pillsbury
esident

John C. Seher
Manager

Sierra
Environmental
Monitoring, Inc.

August 12, 1996

TO: Alpha Analytical

FROM: Sierra Environmental Monitoring, Inc.

RE: Particle Size Distribution Analysis for Samples:

SEM 9608-0213	BMI 080796-01-WUR-SS-1
SEM 9608-0214	BMI 080796-02-WUR-SS-2

As per your request, we have performed particle size analysis on the samples submitted to our laboratory. Test results are as follows:

9608-0213	**Clay: 2.6 %**	**Silt: 0.3 %**	**Sand: 97.1 %**
9608-0214	**Clay: 2.6 %**	**Silt: 0.3 %**	**Sand: 97.1 %**

The samples were passed through a #10 sieve prior to analysis as per procedure. All results are based on oven dry sample weights.

We appreciate this opportunity to provide our laboratory testing services. If you have any questions or require further testing, please feel free to contact us at your convenience.

Sincerely,
SIERRA ENVIRONMENTAL MONITORING, INC.

John Seher
Laboratory Manager

lliam F. Pillsbury
esident

1135 Financial Blvd.
Reno, NV 89502
Phone (702) 857-2400
FAX (702) 857-2404

John C. Seher
Manager

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e-mail: alpha@powernet.net
http//www.powernet.net/~alpha

2505 Chandler Avenue, Suite 1
Las Vegas, Nevada 89120
(702) 498-3312
FAX: 702-736-7523
1-800-283-1183

ANALYTICAL REPORT

Battelle
505 King Ave
Columbus Ohio 43201

Job#: G462201-30B2101
Phone: (614) 424-6199
Attn: Eric Foote

Sampled: 07/31/96 Received: 08/07/96 Analyzed: 08/10-13/96

Matrix: [X] Soil [ ] Water [ ] Waste

Analysis Requested: TPH - Total Petroleum Hydrocarbons-Extractable Quantitated As Diesel
BTEX - Benzene,Toluene,Ethylbenzene,Xylenes

Methodology: TPH - Modified 8015/DHS LUFT Manual/BLS-191
BTEX - EPA Method 624/8240

TPH/BTXE Results:

Client ID/ Lab ID	Parameter	Concentration	Detection Limit
WUR-SS-1	TPH	ND	10 mg/Kg
/BMI080796-01	Benzene	ND	20 ug/Kg
	Toluene	ND	20 ug/Kg
	Ethylbenzene	ND	20 ug/Kg
	Total Xylenes	ND	20 ug/Kg
WUR-SS-2	TPH	ND	10 mg/Kg
/BMI080796-02	Benzene	ND	20 ug/Kg
	Toluene	ND	20 ug/Kg
	Ethylbenzene	ND	20 ug/Kg
	Total Xylenes	36	20 ug/Kg

ND - Not Detected

Approved By: Roger L. Scholl Date: 8/16/96
Roger L. Scholl, Ph.D.
Laboratory Director

Battelle
Columbus Laboratories

CHAIN OF CUSTODY RECORD

Form No. ______

Proj. No. G462201 30B2101

Project Title WURTSMITH PILOT STUDY

SAMPLERS: (Signature) Shane S. Walton

DATE	TIME	SAMPLE I.D.	Boiling Pt. Distribution	BTEX											Container No.	Number of Containers	Remarks
07/29/96	12:00 pm	WUR-FP-1	X	X												1	

Relinquished by: (Signature)	Date/Time	Received by: (Signature)	Relinquished by: (Signature)	Date/Time	Received by: (Signature)
Shane S. Walton	08/06/96 1:30 pm				
Relinquished by: (Signature)	Date/Time	Received by: (Signature)	Relinquished by: (Signature)	Date/Time	Received by: (Signature)

Relinquished by: (Signature)	Date/Time	Received for Laboratory by: (Signature)	Date/Time	Remarks
		[signature]	8/7/96 1000	

Page ____ of ____

Billing Information:
Name
Address
City, State, Zip
Phone Number   Fax

Alpha Analytical, Inc.
255 Glendale Avenue, Suite 21
Sparks, Nevada 89431
Phone (702) 355-1044
Fax (702) 355-0406

Client Name Battelle	P.O. #	Job # G462201-30B2 HV
Address	PWS #	DWR #
City, State, Zip	Phone #	Fax #
Sampled by	Report Attention	

Analyses Required

Time Sampled	Date Sampled	Matrix* See Key Below	Office Use Only Lab ID Number	Sample Description	Total and type of containers ** See below	Boiling Pt. Dist.	BTXE										
	7/29	OT	BMI080796-08	WUR-FP-1	1 OT	X	X										

REMARKS:
Can (Tin)

	Signature	Print Name	Company	Date	Time
Relinquished by					
Received by	[signature]	Linda Bydaick	AAI	8/7/96	1000
Relinquished by					
Received by					
Relinquished by					
Received by					

NOTE: Samples are discarded 60 days after results are reported unless other arrangements are made. Hazardous samples will be returned to client or disposed of at client expense.
[redacted] Key: AQ - Aqueous [redacted] SO - Soil [redacted] WA - Waste [redacted] OT - Other [redacted] **: L-Liter [redacted] V-Voa [redacted] S-Soil Jar [redacted] O-Orbo [redacted] T-Tedlar [redacted] B-Brass [redacted] P-Plastic [redacted] OT-Other [redacted]

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FAX: 702-736-7523
1-800-283-1183

ANALYTICAL REPORT

Battelle
505 King Ave
Columbus Ohio 43201

Job#: G462201-30B2101
Phone: (614) 424-6199
Attn: Eric Foote

Sampled: 07/29/96 Received: 08/07/96 Analyzed: 08/09/96

Matrix: [ ] Soil [ ] Water [X] Other

Analysis Requested: BTEX - Benzene,Toluene,Xylenes,Ethylbenzene

Methodology: BTEX - EPA Method 624/8240

Results:

Client ID/ Lab ID	Parameter	Concentration mg/Kg	Detection Limit mg/Kg
WUR-FP-1	Benzene	ND	440
/BMI080796-08	Toluene	ND	440
	Ethylbenzene	ND	440
	Total Xylenes	10,000	440

ND - Not Detected

Approved by: Roger L. Scholl Date: 8/15/96
Roger L. Scholl, Ph.D.
Laboratory Director

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255 Glendale Avenue, Suite 21
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(702) 498-3312
FAX: 702-736-7523
1-800-283-1183

ANALYTICAL REPORT

Battelle
505 King Ave
Columbus Ohio 43201

Job#: G462201-30B2101
Phone: (614) 424-6199
Attn: Eric Foote

Alpha Analytical Number: BMI080796-08

Client I.D. Number: WUR-FP-1

Date Sampled: 07/29/96

Date Received: 08/07/96

C-range Compounds	Method	Percentage of Total	Detection Limit (Not Applicable)	Date Analyzed
C09<	GC/FID	32.72	NA	08/12/96
C10	GC/FID	17.49	NA	08/12/96
C11	GC/FID	13.00	NA	08/12/96
C12	GC/FID	10.74	NA	08/12/96
C13	GC/FID	7.97	NA	08/12/96
C14	GC/FID	5.98	NA	08/12/96
C15	GC/FID	3.37	NA	08/12/96
C16	GC/FID	2.02	NA	08/12/96
C17	GC/FID	1.63	NA	08/12/96
C18	C/FDI	1.25	NA	08/12/96
C19	GC/FID	0.95	NA	08/12/96
>C20	GC/FID	2.87	NA	08/12/96

Approved by: Roger L. Scholl

Date: 8/15/96

Roger L. Scholl, Ph.D.
Laboratory Director

Alpha Analytical, Inc.
255 Glendale Avenue, Suite 21
Sparks, Nevada 89431
(702) 355-1044
FAX: 702-355-0406
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e-mail: alpha@powernet.net
http//www.powernet.net/~alpha

2505 Chandler Avenue, Suite 1
Las Vegas, Nevada 89120
(702) 498-3312
FAX: 702-736-7523
1-800-283-1183

ANALYTICAL REPORT

Battelle
505 King Ave
Columbus Ohio 43201

Job#: G462201-30B2101
Phone: (614) 424-6199
Attn: Eric Foote

Sampled: 08/02-06/96 Received: 08/07/96 Analyzed: 08/13/96

Matrix: [ ] Soil [X] Water [ ] Waste

Analysis Requested: TPH - Total Petroleum Hydrocarbons-Purgeable Quantitated As Gasoline
BTEX - Benzene,Toluene,Ethylbenzene,Xylenes

Methodology: TPH - Modified 8015/DHS LUFT Manual/BLS-191
BTEX - Method 624/8240

Results:

Client ID/ Lab ID	Parameter	Concentration	Detection Limit
WUR-H2O-1 /BMI080796-03	TPH (Purgeable)	9.6	0.50 mg/L
	Benzene	33	1.0 ug/L
	Toluene	ND	1.0 ug/L
	Ethylbenzene	43	1.0 ug/L
	Total Xylenes	190	1.0 ug/L
WUR-H2O-2 /BMI080796-04	TPH (Purgeable)	2.2	0.50 mg/L
	Benzene	40	1.0 ug/L
	Toluene	ND	1.0 ug/L
	Ethylbenzene	19	1.0 ug/L
	Total Xylenes	140	1.0 ug/L
WUR-H2O-3 /BMI080796-05	TPH (Purgeable)	3.5	0.50 mg/L
	Benzene	37	1.0 ug/L
	Toluene	ND	1.0 ug/L
	Ethylbenzene	17	1.0 ug/L
	Total Xylenes	120	1.0 ug/L
WUR-H2O-4 /BMI080796-06	TPH (Purgeable)	5.1	0.50 mg/L
	Benzene	35	1.0 ug/L
	Toluene	ND	1.0 ug/L
	Ethylbenzene	20	1.0 ug/L
	Total Xylenes	140	1.0 ug/L

Alpha Analytical, Inc.
255 Glendale Avenue, Suite 21
Sparks, Nevada 89431
(702) 355-1044
FAX: 702-355-0406
1-800-283-1183

e-mail: alpha@powernet.net
http//www.powernet.net/~alpha

2505 Chandler Avenue, Suite 1
Las Vegas, Nevada 89120
(702) 498-3312
FAX: 702-736-7523
1-800-283-1183

continued:

Client ID/ Lab ID	Parameter	Concentration	Detection Limit
WUR-H2O-5 /BMI080796-07	TPH (Purgeable)	2.2	0.50 mg/L
	Benzene	35	1.0 ug/L
	Toluene	ND	1.0 ug/L
	Ethylbenzene	21	1.0 ug/L
	Total Xylenes	140	1.0 ug/L

ND - Not Detected

Approved by: Roger L. Scholl Date: 8/16/96
Roger L. Scholl, Ph.D.
Laboratory Director

APPENDIX C

SYSTEM CHECKLIST

Checklist for System Shakedown

Site: WURTSMITH AFB
SITE SS-06

Date: JULY 29, 1996

Operator's Initials: ED/SW/KH

Equipment	Check if Okay	Comments
Liquid Ring Pump	✓	
Aqueous Effluent Transfer Pump	✓	
Oil/Water Separator	✓	
Vapor Flow Meter	✓	
Fuel Flow Meter	✓	
Water Flow Meter	✓	
Emergency Shut off Float Switch -Effluent Transfer Tank	✓	
Analytical Field Instrumentation -GasTechtor O_2/CO_2 Analyzer -TraceTechtor Hydrocarbon Analyzer -Oil/Water Interface Probe -Magnehelic Boards -Thermocouple Thermometer	 ✓ ✓ ✓ ✓ ✓	EXTRA EQUIPMENT FILTER TANK ✓ ADDITIONAL FLOAT SWITCHES ✓ REINJECTION BLOWER ✓

APPENDIX D

DATA SHEETS FROM THE SHORT-TERM PILOT TEST

Bioslurping Pilot Test
(Data Sheet 1)
Well Characteristics

Site: WURTSMITH AFB
SITE SS-06

Test Type (skimmer, bioslurper vacuum extraction, drawdown): BIOSLURPER #1 - WELL #H192S

Depth to Groundwater: 27.26' Depth to Fuel: 27.09' Depth of Slurper Tube: 27.25'

Date at Start of Test: 8/1/96

Time at Start of Test: 7:00 PM

Operator's Initials: ED/SW/KH

Date/Time	Well ID: #H192S			Well ID:			Well ID:		
	LNAPL Level	Water Level	Drop Tube Level ~~Pressure (In H_2O)~~	LNAPL Level	Water Level	Pressure (In H_2O)	LNAPL Level	Water Level	Pressure (In H_2O)
8/1/96	27.09'	27.26'	27.25'						
	27.00'	27.05'	27.00'						
	26.85'	26.90'	26.90'						

Figure 11. Typical Record Sheets for Bioslurper Pilot Testing

Baildown Test Record Sheet

Site: WURTSMITH AFB SITE SS-06

Well Identification: #H192S

Well Diameter (OD/ID): 4"

Sampler's Initials: ED/SW/KH

Date at Start of Test: 12:00 PM

Time at Start of Test: 7/29/96

Initial Readings

Depth to Groundwater (ft)	Depth to LNAPL (ft)	LNAPL Thickness (ft)	Total Volume Bailed (L)
28.03	27.17	0.86	3.5

Test Data

Sample Collection Time	Depth to Groundwater (ft)	Depth to LNAPL (ft)	LNAPL Thickness (ft)
12:10 (T=0)	27.48	27.23	0.25
12:35	27.54	27.22	0.32
14:24	27.76	27.17	0.59
16:30	27.84	27.14	0.70
18:40	27.87	27.14	0.73
19:53	27.89	27.13	0.76
7:35 (7/30/96)	27.82	27.09	0.73

Figure 9. Typical Baildown Test Record Sheet

Baildown Test Record Sheet

Site: WURTSMITH AFB SITE SS-06

Well Identification: #H196S

Well Diameter (OD/ID): 4"

Date at Start of Test: 12:15pm

Time at Start of Test: 7/29/96

Sampler's Initials: ED/SW/KH

Initial Readings

Depth to Groundwater (ft)	Depth to LNAPL (ft)	LNAPL Thickness (ft)	Total Volume Bailed (L)
28.79	28.02	0.77	3.0

Test Data

Sample Collection Time	Depth to Groundwater (ft)	Depth to LNAPL (ft)	LNAPL Thickness (ft)
12:25 (T=0)	28.33	28.12	0.21
12:50	28.34	28.12	0.22
14:27	28.35	28.12	0.23
16:43	28.35	28.11	0.24
18:50	28.34	28.11	0.23
7:40 (7/30/96)	28.36	28.07	0.29

Figure 9. Typical Baildown Test Record Sheet

Bioslurping Pilot Test
(Data Sheet 3B)
Fuel and Water Recovery Data

Site: WURTSMITH AFB- SITE SS06 Test Type: SKIMMER # 1 (PARASTALTIC PUMP)

Start Date: 7/30/96 Operators: ED / SW / KH

Date/Time	Run Time	LNAPL Recovery (volume collected in time period)	Groundwater Recovery (volume collected in time period)
7/30/96 11:30AM	0	0	Total = (0)
1:00PM	1.5	1.0	(7) 7
6:00PM	6.5	0.25	(45) 38
8:00PM	8.5	0.1	(55) 10
7/31/96 12:00AM	12.5	0.25	(80) 25
7:00AM	19.5	0.15	(120) 40
10:00AM	22.5	0.25	(140) 20
3:00PM	27.5	0.15	(170) 30
7:00PM	31.5	0.15	(195) 25
11:00PM	35.5	0.15	(220) 25
8/1/96 3:30AM	40.0	0.15	(250) 30
9:00AM	45.5	0.15	(285) 35
11:30AM	48.0	0	(300) 15
	Total =	2.75 gallons	300 gallons
		Based on total accumulated	Based on flow rates recorded

Bioslurping Pilot Test
(Data Sheet 3B)
Fuel and Water Recovery Data

Page 1 of 1

Site: WURTSMITH AFB - SITE SS06　　Test Type: BIOSLURPER #1

Start Date: 8/1/96　　Operators: ED/SW/KH

	Date/Time	Run Time	LNAPL Recovery (volume collected in time period)	Groundwater Recovery (volume collected in time period)
Full Vac	8/1/96 7:00PM	0	0	Total = (0)
	9:00PM	2	0.5	(800) 800
1/2 Vac	8/2/96 8:00AM	13	1.25	(3,233) 2,433
	12:00PM	17	0	
	7:00PM	24	0.75	(5,223) 1,990
	8/3/96 10:30AM	39.5	0.75	(7,121) 1,898
	7:00PM	48	0.75	(8,240) 1,119
Full Vac	8/4/96 11:00AM	63	0.25	(10,369) 2,129
	1:00PM	66	0.15	
	6:30PM	71.5	0.1	(11,433) 1,064
	8/5/96 11:00AM	88	0	(13,675) 2,242
	6:00PM	95	0	(14,772) 1,097
				+208 to fill filter box and oil/water separator
		Total =	4.5 gallons	14,980 gallons

Bioslurping Pilot Test
(Data Sheet 3B)
Fuel and Water Recovery Data

Site: WURTSMITH AFB - SITE SS06 Test Type: SKIMMER # 2

Start Date: 8/5/96 Operators: ED/SW/KH

Date/Time	Run Time	LNAPL Recovery (volume collected in time period)	Groundwater Recovery (volume collected in time period)
8/5/96 6:30AM	0	0	Total = (0)
10:30AM	4	0	(180) 180
8/6/96 10:00AM	15.5	0	(665) 485
5:00PM	22.5	0	(778) 113
	Total =	0 gallons	778 gallons

Bioslurping Pilot Test
(Data Sheet 3B)
Fuel and Water Recovery Data

Site: WURTSMITH AFB - SITE SS06 Test Type: DRAWDOWN

Start Date: 8/6/96 Operators: ED/SW/KH

Date/Time	Run Time	LNAPL Recovery (volume collected in time period)	Groundwater Recovery (volume collected in time period)
8/6/96 5:30PM	0	0	Total = (0)
10:30PM	5	0	(613) 613
8/7/96 1:00PM	19.5	0	(1,166) 553
6:00PM	24.5	0	(1,943) 777
			+157 gallons to refill
			OWS
	Total=	0 gallons	2,100 gallons

Bioslurping Pilot Test
(Data Sheet 3B)
Fuel and Water Recovery Data

Site: WURTSMITH AFB - SITE SS06 Test Type: BIOSLURPER #2

Start Date: 8/7/96 Operators: ED/SW/KH

Date/Time	Run Time	LNAPL Recovery (volume collected in time period)	Groundwater Recovery (volume collected in time period)
8/7/96 8:10PM	0	0	Total = (0)
11:10PM	3	0.75	(720) 720
8/8/96 1:10AM	5	0.25	(1,043) 323
9:45AM	13.5	0.25	(2,810) 1,767
	Total =	1.25 gallons	2,810 gallons

APPENDIX E

SOIL GAS PERMEABILITY TEST RESULTS

BATTELLE	RECORD SHEET FOR AIR PERMEABILITY TEST				DATE/TIME:
DISTANCE FROM VENT WELL (ft. & tenths)	9' SOUTH OF #H192S	15' SOUTH OF #H192S	30' SOUTH OF #H192S		SITE: WURTSMITH AFB SITE SS-06
TIME FROM START-UP (MIN.)	PT. CODE	PT. CODE	PT. CODE	PT. CODE	RECORDED BY: ED/SW/KH
	WU-MPA-A DEPTH = 11.0'	WU-MPB-A DEPTH = 11.0'	WU-MPC-A DEPTH = 11.0'		COMMENTS
	PRESSURE (IN H_2O)	PRESSURE (IN H_2O)	PRESSURE (IN H_2O)	PRESSURE (IN H_2O)	
0	–	–	–		
11	0.045	0.055	0.06		
15	0.04	0.055	0.06		
21	0.045	0.055	0.06		
50	0.05	0.06	0.065		
80	0.045	0.06	0.06		
140	0.045	0.06	0.06		
1,080	0.12	0.055	0.015		

BATTELLE	RECORD SHEET FOR AIR PERMEABILITY TEST				DATE/TIME:
DISTANCE FROM VENT WELL (ft. & tenths)	9' SOUTH OF #H192S	15' SOUTH OF #H192S	30' SOUTH OF #H192S		SITE: WURTSMITH AFB SITE SS-06
TIME FROM START-UP (MIN.)	PT. CODE	PT. CODE	PT. CODE	PT. CODE	RECORDED BY: ED/SW/KH
	WU-MPA-B DEPTH=15.0'	WU-MPB-B DEPTH=16.0'	WU-MPC-B DEPTH=16.0'		COMMENTS
	PRESSURE (IN H_2O)	PRESSURE (IN H_2O)	PRESSURE (IN H_2O)	PRESSURE (IN H_2O)	
0	—	—	—		
11	0.05	0.075	0.0		
15	0.05	0.08	0.0		
21	0.06	0.08	0.0		
50	0.06	0.095	0.001		
80	0.06	0.095	0.001		
140	0.06	0.095	0.001		
1,080	0.245	0.115	0.005		

BATTELLE	RECORD SHEET FOR AIR PERMEABILITY TEST				DATE/TIME:
DISTANCE FROM VENT WELL (ft. & tenths)	9' SOUTH OF #H192S	15' SOUTH OF #H192S	30' SOUTH OF #H192S		SITE: WURTSMITH AFB SITE SS-06
TIME FROM START-UP (MIN.)	PT. CODE	PT. CODE	PT. CODE	PT. CODE	RECORDED BY: ED/SW/KH
	WU-MPA-C DEPTH=16.0'	WU-MPB-C DEPTH=16.0'	WU-MPC-C DEPTH=16.0'		COMMENTS
	PRESSURE (IN H_2O)	PRESSURE (IN H_2O)	PRESSURE (IN H_2O)	PRESSURE (IN H_2O)	
0	–	–	–		
11	0.06	0.145	0.28		
15	0.06	0.145	0.28		
21	0.055	0.145	0.28		
50	0.095	0.18	0.30		
80	0.09	0.175	0.29		
140	0.85	0.170	0.29		
1,080	0.80	0.25	0.035		

APPENDIX F

IN SITU RESPIRATION TEST RESULTS

Record Sheet for In Situ Respiration Test

Site	WURTSMITH AFB - SITE SS-06	Monitoring Point	WU-MPA-RED (C) (DEPTH = 21.0')
Shutdown Date	8/7/96	O_2/CO_2 Meter No.	TPH Meter No.
Shutdown Time	10:30 AM	Recorded by	SHANE WALTON / KIP HEWAHEWA

Date	Time	O_2 (%)	CO_2 (%)	TPH (ppm)	He (%)	Temperature (°C)	Comments
8/5/96	6:15pm	18.3	2.1	8,000	–	–	Initial Readings before Injection
8/7/96	10:30am						Shut down start.
	10:30am	20.1	0.5	40	0.68	–	
	10:48am	20.1	0.0	22	1.2	–	
	12:40pm	20.0	0.4	100	1.5	–	
	17:45pm	20.1	0.75	3,100	0.36	–	Low battery on He detector
	20:55pm	20.0	1.5	1,500	0.5	–	Low battery on He detector
8/8/96	10:00am	17.9	1.0	2,800	0.61	–	
	13:00pm	17.0	1.3	2,800	0.0	14.9°C	
2nd shutdown test - Shutdown Time @ 10:00am on 8/9/96							
8/9/96	10:12am	20.0	0	0	1.8	–	
	12:10pm	19.9	0.6	0	1.5	–	
	14:18pm	19.8	0.5	0	1.9	–	
	17:17pm	19.5	0.6	250	2.9	–	
	21:32pm	19.5	0.7	540	2.6	–	
8/10/96	8:30am	17.9	0.8	1,200	2.9	–	
	13:00pm	17.9	0.8	1,400	2.6	–	
	17:00pm	17.0	1.2	1,800	3.0	–	
8/11/96	8:56am	15.5	1.7	2,800	2.5	–	

INSITU.RS (G462201-1001 DIS)

Record Sheet for In Situ Respiration Test

Site WURTSMITH AFB - SITE SS-06

Monitoring Point WU-MPB-RED (C) (DEPTH = 21.0')

Shutdown Date 8/7/96

O_2/CO_2 Meter No.

TPH Meter No.

Shutdown Time 10:30am

Recorded by SHANE WALTON / KIP HEWAHEWA

Date	Time	O_2 (%)	CO_2 (%)	TPH (ppm)	He (%)	Temperature (°C)	Comments
8/5/96	6:15pm	17.2	2.0	7,800	-	-	Initial Readings before injection
8/7/96	10:30am						Shut down start
	10:33am	20.1	0.25	50	1.6	-	
	10:50am	20.1	0.5	46	1.2	-	
	12:43pm	20.1	0.25	2,400	1.4	-	
	17:48pm	20.1	0.6	4,100	0.37	-	Low battery on He detector
	20:57pm	19.2	1.5	8,500	0.5	-	Low battery on He detector
8/8/96	10:05am	19.0	0.9	5,500	0.52	-	
	13:05pm	18.7	1.1	7,200	0.8	-	
2nd Shutdown test -	Shutdown	Time @ 10:00am on 8/9/96					
8/9/96	10:20am	20.0	0	0	3.4	-	
	12:20pm	19.8	0.6	900	1.3	-	
	14:24pm	19.9	0.5	1,200	2.0	-	
	17:25pm	19.1	0.5	2,400	0	-	
	21:37pm	19.1	0.6	3,800	2.2	-	
8/10/96	8:37am	18.0	0.8	5,600	1.1	-	
	13:05pm	17.9	0.75	6,200	3.0	-	
	17:13pm	17.9	1.1	7,000	2.2	-	
8/11/96	9:02am	16.0	1.2	9,600	1.9	-	

INSITU.RS (G462201-1001 DISK

Record Sheet for In Situ Respiration Test

Site WURTSMITH AFB - SITE SS-06	Monitoring Point WU - MPC - RED (C) (DEPTH = 21.0')
Shutdown Date 8/7/96	O_2/CO_2 Meter No. / TPH Meter No.
Shutdown Time 10:30 am	Recorded by SHANE WALTON / KIP HEWAHEWA

Date	Time	O_2 (%)	CO_2 (%)	TPH (ppm)	He (%)	Temperature (°C)	Comments
8/5/96	6:15 pm	19.0	1.0	7,400	–	–	Initial Readings before injection
8/7/96	10:30 am						Shut down start.
	10:36 am	20.1	0.0	58	0.88	–	
	10:52 am	20.1	0.5	30	1.1	–	
	12:45 pm	20.1	0.0	200	1.0	–	
	17:51 pm	20.1	0.6	1,250	0.0	–	Low battery on He detector
	21:00 pm	19.9	0.9	8,800	0.1	–	Low battery on He detector
8/8/96	10:00 am	19.1	0.9	5,400	0.67	–	
	10:~~10~~ am	19.0	0.7	5,500	0.0	–	
2nd Shutdown test -	Shutdown Time = 10.00 am on 8/9/96						
8/9/96	10:~~06~~ am	20.0	0.0	0	2.3	–	
	12:28 pm	19.5	0.5	0	1.5	–	
	14:30 pm	19.9	0.6	0	1.9	–	
	17:31 pm	19.1	0.5	220	1.9	–	
	21:44 pm	19.8	0.5	450	1.2	–	
8/10/96	8:45 am	18.8	0.6	1,000	1.4	–	
	13:11 pm	18.5	0.75	1,500	2.1	–	
	17:18 pm	18.5	0.6	1,600	2.1	–	
8/11/96	9:09 am	17.0	0.75	2,800	2.6	–	

INSITU.RS (G462201-1001 DISK