RESULTS OF A MULTI-SITE FIELD TREATABILITY TEST FOR BIOSLURPING: A COMPARISON OF LNAPL RATES USING VACUUM-ENHANCED RECOVERY (BIOSLURPING), PASSIVE SKIMMING, AND PUMP DRAWDOWN RECOVERY TECHNIQUES

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Bioslurping is a new dynamic technology designed to efficiently recover free-floating petroleum hydrocarbons (free product) from the subsurface while simultaneously enhancing natural biodegradation of petroleum hydrocarbons in the vadose zone. Bioslurping is a vacuum-enhanced fluids pumping technology that simultaneously extracts groundwater, free product, and soil gas in the same process stream. The U.S. Air Force has initiated a multi-site program to evaluate the widespread application of bioslurping at free product-contaminated Air Force sites. The Air Force Bioslurper Initiative is designed to access the field application of the bioslurping technology at 36 Air Force sites. The field studies are designed to evaluate the efficacy of bioslurping for the recovery of free-floating fuel (free product) and to evaluate the potential for bioventing to enhance natural biodegradation of petroleum contaminants.

The technical approach for conducting the bioslurper pilot tests includes assessing the geologic and hydrologic characteristics of each site, free-product baildown testing in site monitoring wells, soil gas analysis, and a bioslurper pump test. Bioslurping free-product recovery efficiency is compared to conventional skimming and dual-pump free-product recovery technologies, and bioventing potential is assessed via in situ respiration testing. The Air Force field program was initiated in July 1994. At the time of this writing, seven field tests have been completed. At each site bioslurping has yielded the highest LNAPL recovery rate. This paper presents a summary of LNAPL recovery data to date. Operational issues such as permitting and treatment of vapor and wastewater discharge will be discussed.

Introduction

This paper presents results to date of field testing conducted under 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 multi-site program designed to evaluate the efficacy of bioslurping technology for (1) recovery of light, nonaqueousphase liquid (LNAPL) from groundwater and the capillary fringe, and (2) enhancement of natural in situ biodegradation of petroleum contaminants in the vadose zone via bioventing.

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 to 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 purpose of the 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. Although bioslurping had been demonstrated to enhance LNAPL recovery at a large field site (Kitrel et al., 1994), its efficacy relative to other LNAPL recovery technologies had not been fully investigated. The Bioslurper Initiative on-site testing was structured to allow direct comparison of LNAPL recovery achieved by bioslurping with the performance of more conventional LNAPL recovery technologies. The test method included an initial evaluation of site variables followed by LNAPL recovery testing. The three technologies used to recover free LNAPL floating on the water table are skimmer pumping, bioslurping, and drawdown pumping. This paper presents results of the comparative LNAPL recovery rates by each technique used at the sites completed to date. An overview of the techniques utilized to perform the Bioslurper Initiative field testing is presented below. An in-depth presentation of the Bioslurper Initiative field procedures has been published elsewhere (Leeson et al., 1995).

Bioslurper Technology

Bioslurping is a new dynamic technology that utilizes construction vacuum dewatering technology to facilitate vacuum-assisted free-product recovery and bioventing to simultaneously recover free product and remediate the vadose zone. Unlike other LNAPL recovery technologies, bioslurping systems treat two separate geologic media simultaneously. Bioslurping pumps are designed to extract free-phase LNAPL from the water table and to aerate vadose zone soils through soil gas vapor extraction. The bioslurper system also can be designed to achieve hydraulic control as is done with conventional pump-and-treat technology. The system withdraws groundwater, free product, and soil gas in the same process stream using a single pump. Groundwater is separated from the free product and is treated (when required) and discharged. Free product is recovered and can be recycled. Soil gas vapor is treated (when required) and discharged.

Bioslurping may improve free-product recovery efficiency without requiring the extraction of large quantities of groundwater. The bioslurper system pulls a vacuum of up to 20 inches of mercury on the recovery well to create a pressure gradient to force movement of LNAPL into the well. The system is operated to cause very little drawdown in the aquifer, thus reducing the problem of free-product entrapment in the aquifer.

Bioventing of the vadose zone soils is achieved by withdrawing soil gas from the recovery well. The slurping action of the bioslurper system cycles between recovering liquid (free product and/or groundwater) and soil gas. The rate of soil gas extraction is dependent on the recovery rate of liquid into the well. When free-product removal activities are complete, the bioslurper system is easily converted to a conventional bioventing system to complete remediation of the vadose zone soils.

Bioslurper systems are designed to minimize environmental discharges of groundwater and soil gas. As done in bioventing, bioslurper systems extract soil gas at a low rate to reduce volatilization of contaminants. In some instances volatile discharges can be kept below treatment action levels. The slurping action of a bioslurping system greatly reduces the volume of groundwater that must be extracted compared to conventional LNAPL recovery systems, thus greatly reducing groundwater treatment costs.

A significant feature of the bioslurping process is the induced airflow, which in turn induces LNAPL flow toward the well. The pressure gradient created in the air phase results in a driving force on the LNAPL that is significantly greater than that which can be induced by pumping the LNAPL with no airflow. Also of importance is the fact that the airflow created by the vacuum actually enhances the LNAPL content around the well. That is, the LNAPL tends to accumulate or pile up around the well. The accumulation around the well ensures that the permeability controlling the conductivity to LNAPL is maximum. For these reasons, bioslurping has the potential for removing more LNAPL and at greater rates than do other pumping mechanisms.

Pilot Test Procedures

The U.S. Air Force has selected sites to participate in the Bioslurper Initiative that represent a broad cross section of LNAPL types, geologic/hydrogeolgic environments, and regulatory settings. To ensure consistency in testing procedures, the Test *Plan and Technical Protocol for Bioslurping* (Battelle, 1995) was developed as overall guidance to support preparation of site specific Test Plans for each of the more than 35 sites where short-term field tests will be conducted (Figure 1). The overall protocol contains details on the general materials and methods for bioslurper testing. The bioslurper protocol was developed from a similar protocol for bioventing (Hinchee et al., 1992).

Table 1 presents the schedule of activities for each short-term pilot test. Initial site characterization activities are conducted to evaluate site variables that may affect LNAPL recovery efficiency, and to determine the bioventing potential of the sites. These activities include estimating the persistence of LNAPL in site monitoring wells through baildown tests, soil sampling to determine physical/chemical site characteristics, determining soil gas permeability to estimate the well's radius of influence, and in situ respiration testing to evaluate microbial activity. The site characterization approach is aimed at providing data to assist in determining the feasibility of product recovery as well as aid in the design of the pilot- or full scale system.

Following the site characterization activities, a short-term bioslurper pilot test is conducted. A bioslurper system is installed on a single selected well and typically is operated as follows: 2 days in the skimmer mode (no vacuum); 4 days in the bioslurper mode (vacuum-mediated); 1 day in the skimmer mode (follow-up repeatability test); and 2 days in the groundwater depression mode. Measurements of the extracted soil gas composition, free-product thickness, and groundwater level are made during the pilot test. The volume of extracted free product is quantified over time. These measurements are used to evaluate the long-term effectiveness of bioslurping.

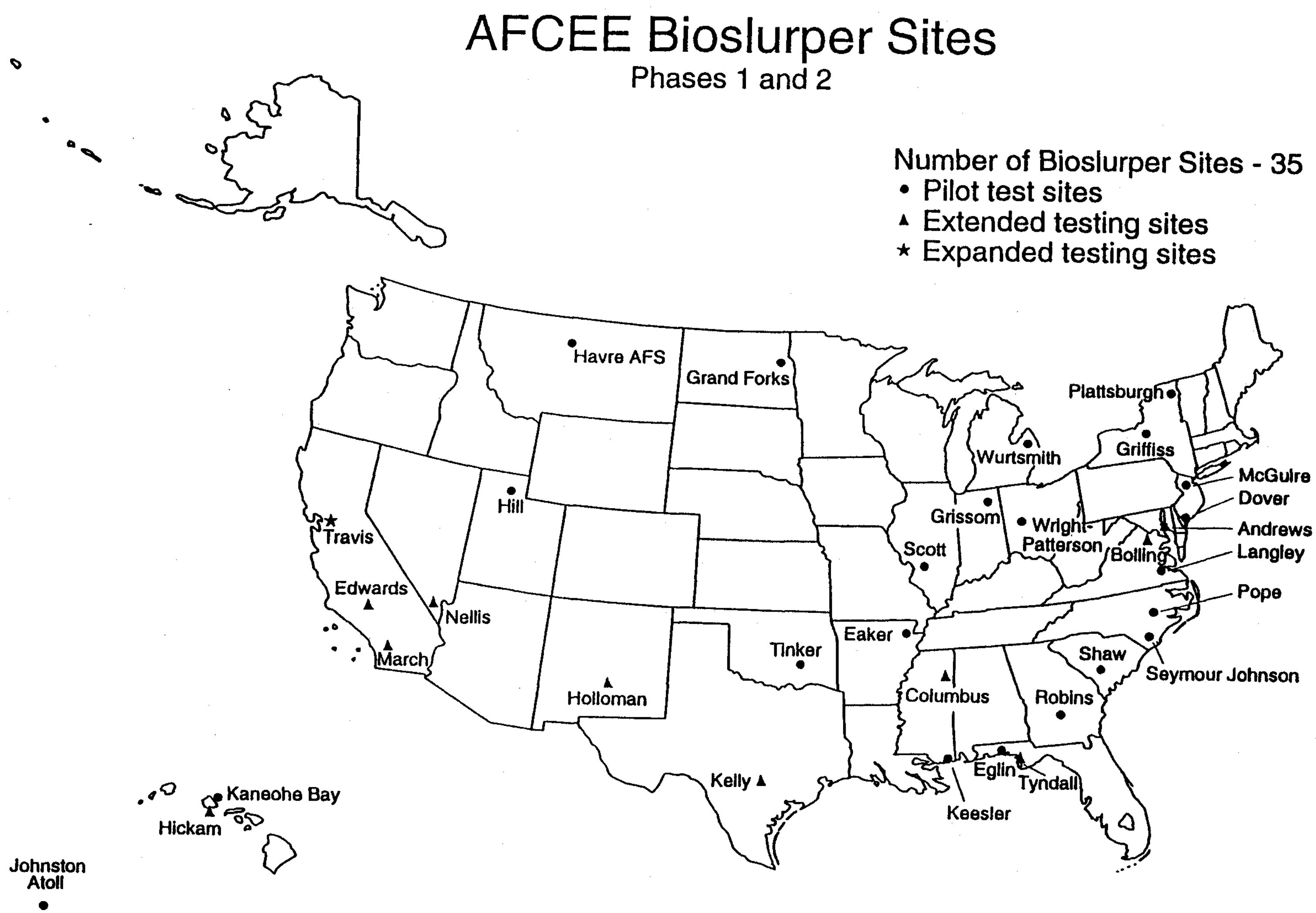

Figure 1. AFCEE Bioslurper Initiative Sites (Phases 1 and 2).

The U. S. Air Force has already installed monitoring points or other wells at many sites that are suitable for use in this study. In keeping with the objective of developing a cost-effective program for site remediation, every effort is made to use existing wells and to minimize drilling costs.

Table 1. Schedule of Activities for Bioslurper Initiative

Pilot Test Activity	Schedule
Mobilization	day 1-2
Site Characterization	day 2-3
Baildown Tests	
Slug Test	
Soil Gas Survey (limited)	
Monitoring Point Installation (3 MPs, multiple depths)	
Soil Sampling (TPH, BTEX, and Physical Characteristics only)	
System Installation	day 2-3
Test Startup	day 4
Slimmer Test (2 days)	day 4-5
Bioslurper Pump Test (4 days)	day 6-10
Soil Gas Permeability Testing	day 6
Skimmer Test (continued)	day 11
Drawdown Pump Test (2 days)	day 12
In Situ Respiration Test (air injection only)	day 12
Demobilization/Mobilization	day 13-14

The Bioslurper Initiative short-term pilot test consists of three different LNAPL recovery tests from a single extraction well. At each site the well that appears to have the highest potential for LNAPL recovery is selected for testing. The bioslurper trailer-mounted pilot system is connected to the well via a 1-inch-diameter pvc droptube. Each trailer-mounted unit includes a bioslurper liquid ring pump (3-hp to 7.5-hp), a gasoline- or diesel-powered electrical generator capable of supplying all power requirements for the pilot testing, an oil/water separator with 10- gpm flow capacity, a transfer tank and pump for directing extracted groundwater to the base--supplied effluent disposition system, and vapor treatment equipment (Figure 2).

The drop tube is positioned at the oil/water interface in the well. The selection of the depth of the drop tube is based on observations made of changes in water levels during the baildown test to compensate for depression of the water level in the well caused by excessive LNAPL thicknesses. The position of the drop tube is the same for skimmer and bioslurper test configurations. During the skimmer test the well is open to the atmosphere (no vacuum), during the bioslurper test the wellhead is sealed vacuum tight with a sanitary well seal. For the pump drawdown test the drop tube is set 1 to 3 ft below the oil/water interface in the well, with the well open to the atmosphere.

Results

Short-term pilot tests have been completed at 11 sites at the time of this writing. Table 2 identifies the sites where testing has been completed and summarizes site characteristic data for each site. A summary of LNAPL recovery data for each pilot test is presented in Table 3. The amount of LNAPL recovered is shown in terms of gallons per day for each of the technologies tested. At 9 of the 11 sites, the bioslurping configuration recovered more LNAPL than either the skimmer or drawdown configurations; in some cases, nearly an order of magnitude increase was observed in LNAPL recovery rates. At Hickam AFB, the drawdown configuration recovered LNAPL at a higher rate than did bioslurping. However, upon further inspection of the extraction well after testing was completed, it was discovered that the well's screen extended to near the ground surface, causing short-circuiting of the vacuum to the atmosphere. At Travis AFB bioslurping and drawdown testing recovered LNAPL at approximately the same rates. At the Travis site it was necessary to dewater during each phase of the testing to facilitate any LNAPL recovery due to an unusually high water table caused by heavy rains.

It should be noted that the average LNAPL recovery rates presented in Table 3, while accurately portraying the relative LNAPL recovery rates of each test configuration, do not necessarily represent long-term sustainable LNAPL recovery rates. Figures 3 through 7 present graphs of representative LNAPL recovery curves observed during the testing. Generally, in each test configuration the LNAPL recovery rate is much higher at the start of the test than at the end of the test. After 4 days of extraction in the bioslurper mode, the LNAPL recovery rates are still higher than for skimming or drawdown testing which are operated for shorter time periods.

Vapor and Wastewater Treatment Issues

The relative costs of bioslurper implementation are being evaluated as part of the Bioslurper Initiative. Of particular importance are the costs of vapor and groundwater discharge treatment. The vapor discharge characteristics vary widely from site to site largely due to site-specific LNAPL composition and system flow rate (Table 4). In addition to having variable discharge characteristics, vapor treatment requirements vary greatly depending on the state and locality of the test site. In general, sites where the LNAPL is less volatile than JP-4 jet fuel (JP-5, diesel, fuel oil, etc.) have not required vapor treatment prior to discharge. At sites where the LNAPL is equal to or more volatile than JP-4 (AVGAS, gasoline, etc.), vapor treatment often has been required. Vapor treatment options are similar to those available for soil venting projects. Due to the relatively short-term nature of LNAPL recovery projects, the use of internal combustion engines appears to be an attractive treatment option.

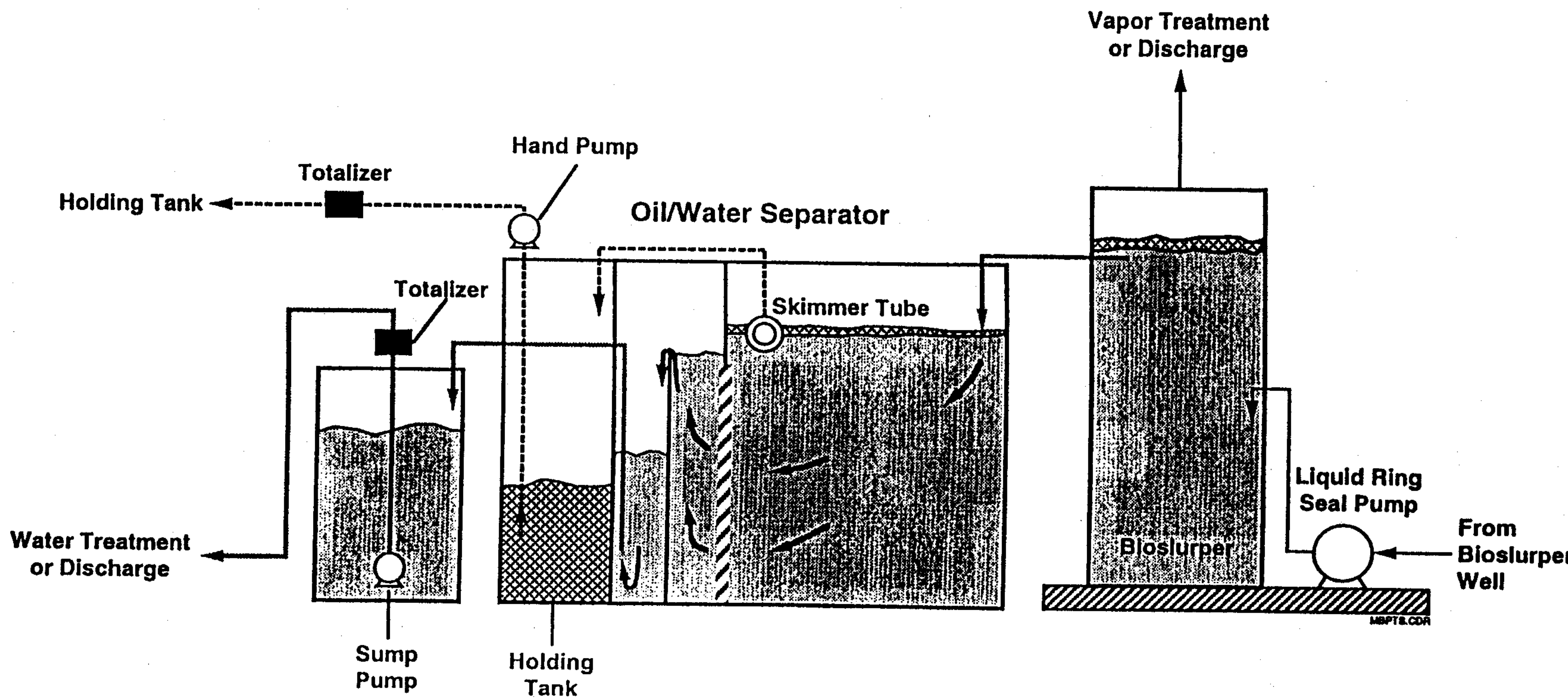

Figure 2. Diagram of Trailer-Mounted Bioslurper Pilot Test System

Table 2. Bioslurper Initiative Site Characteristic Summary Data

Base Location	Site ID	LNAPL Type	Depth to Water (ft)	Initial Fuel Thickness (ft)	Fuel Thickness After 24 hr Baildown Test (ft)	Extraction Well Diameter (in)
Bolling AFB, D.C.	Bldg. 18	fuel oil	23.65	4.44	3.52	2
Bolling AFB, D.C.	Bldg. 41	gasoline	19.06	0.34	0.34	4
Andrews AFB, MA	Bldg. 1845	fuel oil	15.36	2.32	2.01	4
Wright-Patterson AFB, OH	Well P6-2	JP-4	20.69	0.12	0.05	2
Travis AFB, CA	JFSA-1	JP-4	8.7	NA[1]	NA	6
Robins AFB, GA	UST 70/72	JP-4	8.5	6.67	1.83	4
Robins AFB, GA	SS010	JP-4	7.3	6.78	0.16	2
Kaneohe MCBH, HI	POL Tank Farm	JP-5	17.54	1.13	0.24	2
Hickam AFB, HI	Area H	AVGAS	18.59	3.98	3.95	4
Johnston Atoll DNA	Tank 41	JP-5	7.78	0.44	0.57	2

[1] A skimmer LNAPL recovery system was operating at this site prior to beginning field testing.

Table 3. Bioslurper Initiative Comparative Fuel Recovery Rates and Bioventing Feasability Study

Base Location	Site ID	Average Fuel Recovery (gal/day)				Soil Gas Radius of Influence (ft)	Biodegradation Rate (mg/kg/day)
		2-Day Skimmer Test	4-day Bioslurper Test	1-Day Skimmer Test	2-Day Drawdown Test		
Bolling AFB, D.C.	Bldg. 18	16.9	59.8	8.2	31.2	45	NA
Bolling AFB, D.C.	Bldg. 41	0.86	1.14	NA	0.13	47	12.9 to 15.3
Andrews AFB, MA	Bldg. 1845	8.7	78.5	0.7	NA	250	21 to 7.5
Wright-Patterson AFB, OH	Well P6-2	4.0	4.65	NA	2.46	10.0	1.3 to 3.2
Travis AFB, CA	JFSA-1	0.0	3.85	0.0	3.76	55.3	61 to 82
Robins AFB, GA	UST 70/72	10.85	47.5	4.96	11.5	56	1.8-3.3
Robins AFB, GA	SS010	1.41	3.22	NA	0.36	76	6.9-10.7
Kaneohe MCBH, HI	POL Tank Farm	0.0	2.39	0.05	0.0	23	60 to 122
Hickam AFB, HI	Area H	34.5	90.9[1]	NA	408.5	NA[1]	5.1 to 21
Johnston Atoll DNA	Tank 41	29.8	56	3.6	9.5	15.0	3.9 to 8.0

NA Test not performed.
[1] Extraction well screen extended to the ground surface causing short-circuting.

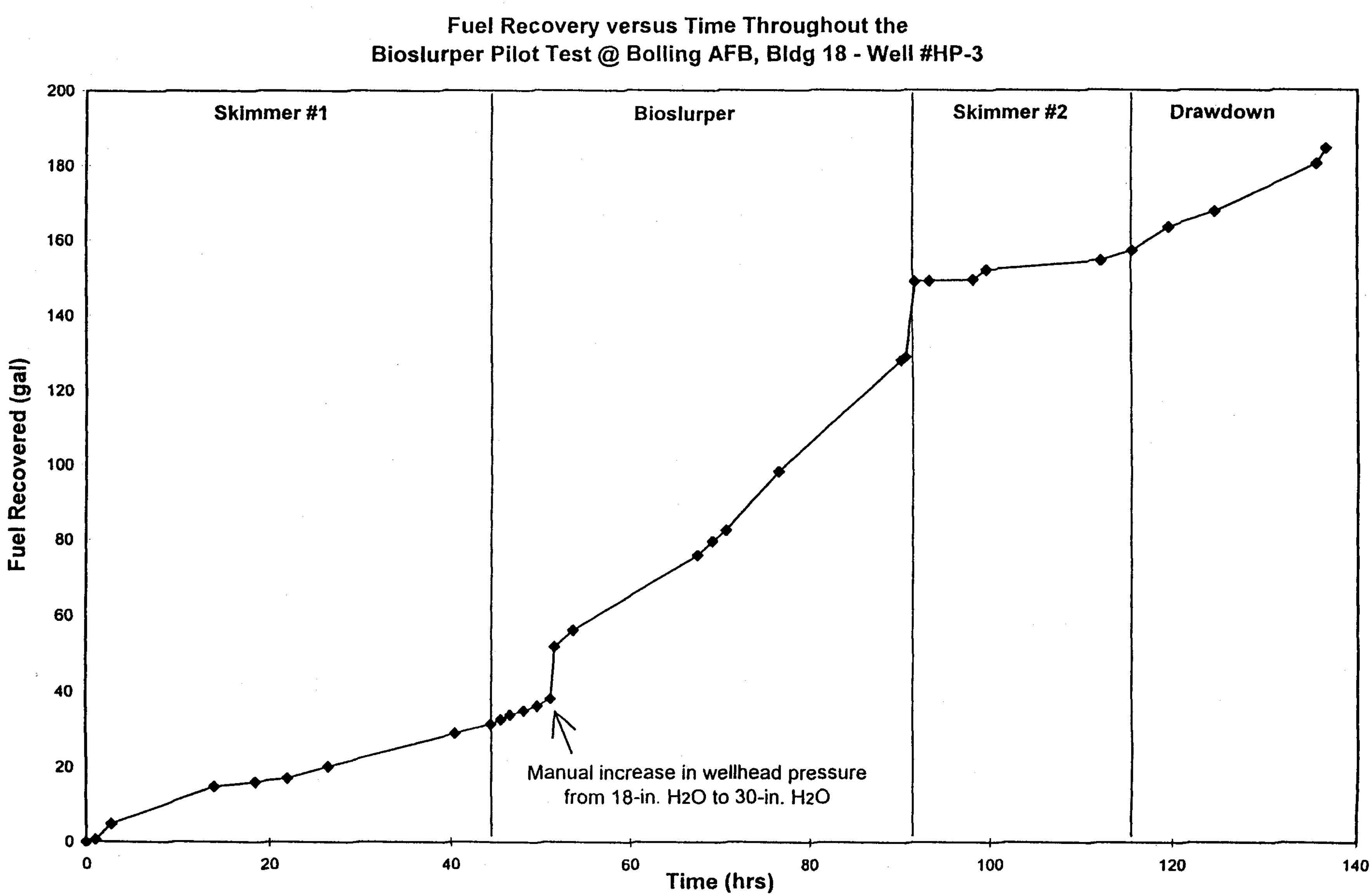

Figure 3. **Fuel Recovery versus Time Throughout the Bioslurper Pilot Test @ Bolling AFB, Bldg. 18 - Well #HP-3**

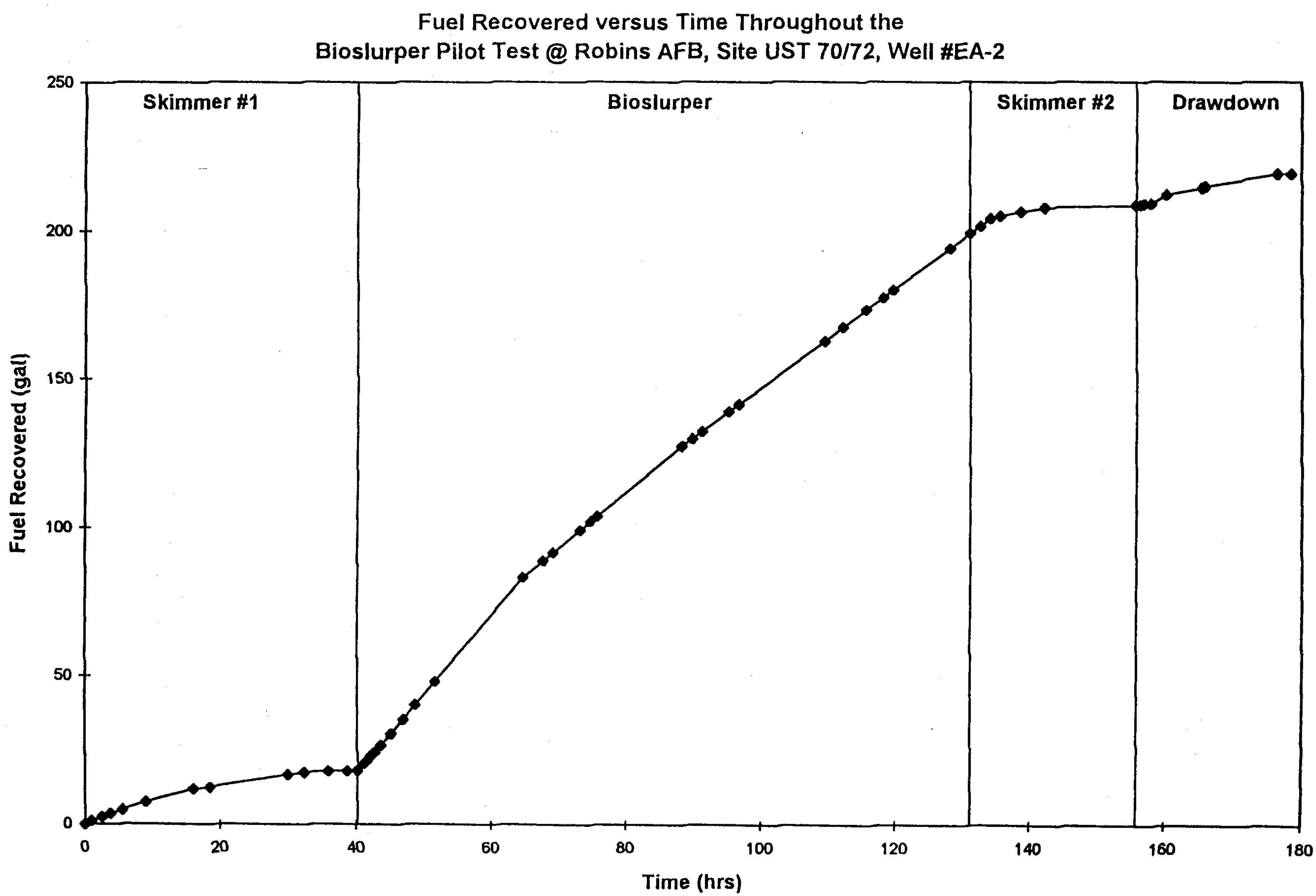

Figure 4. Fuel Recovery versus Time Throughout the Bioslurper Pilot Test @ Robins AFB, Site UST 70/72, Well #EA-2

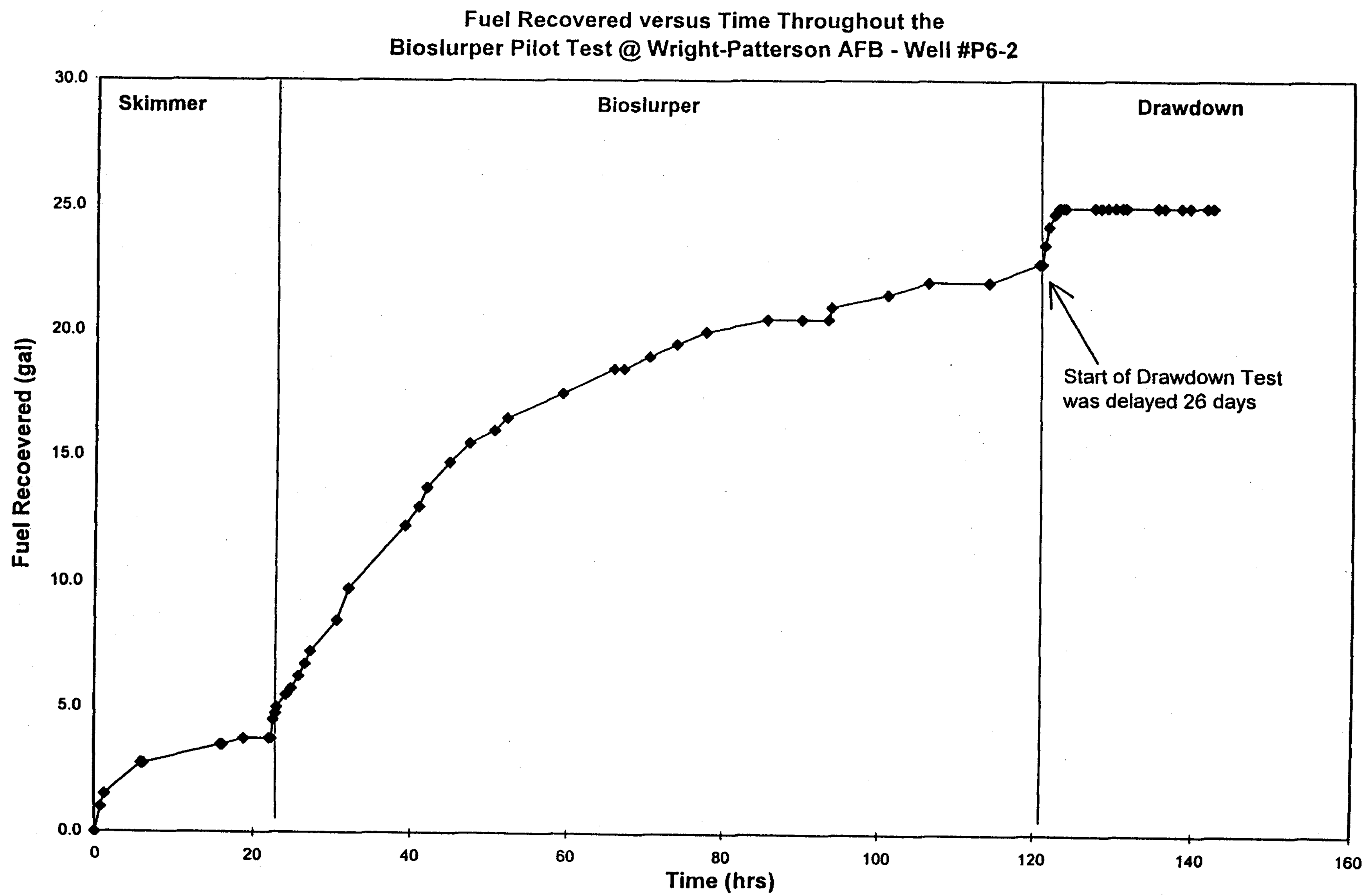

Figure 5. **Fuel Recovery versus Time Throughout the Bioslurper Pilot Test @ Wright-Patterson AFB, Well #P6-2**

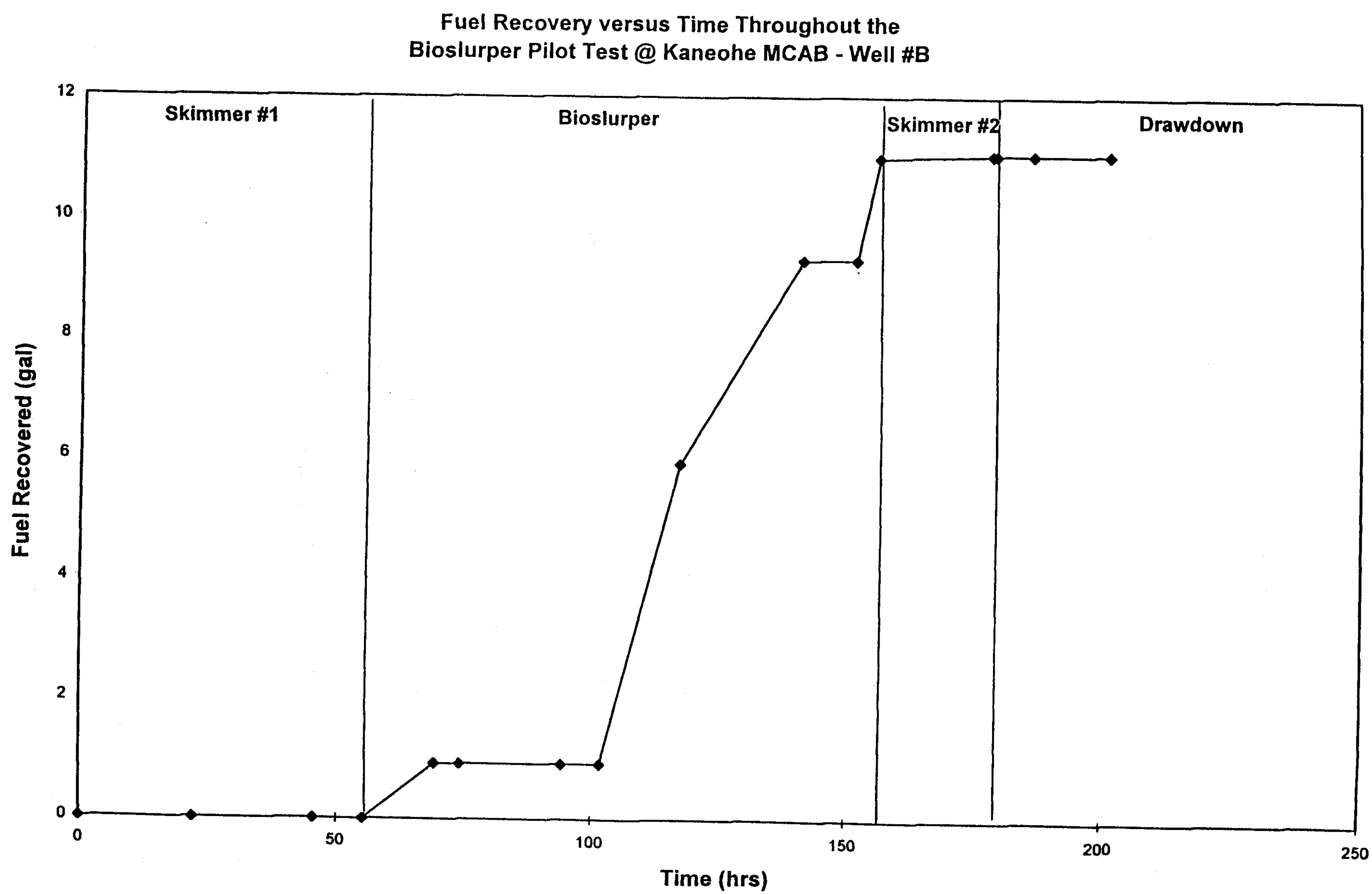

Figure 6. Fuel Recovery versus Time Throughout the Bioslurper Pilot Test @ Kaneohe MCAB - Well #B

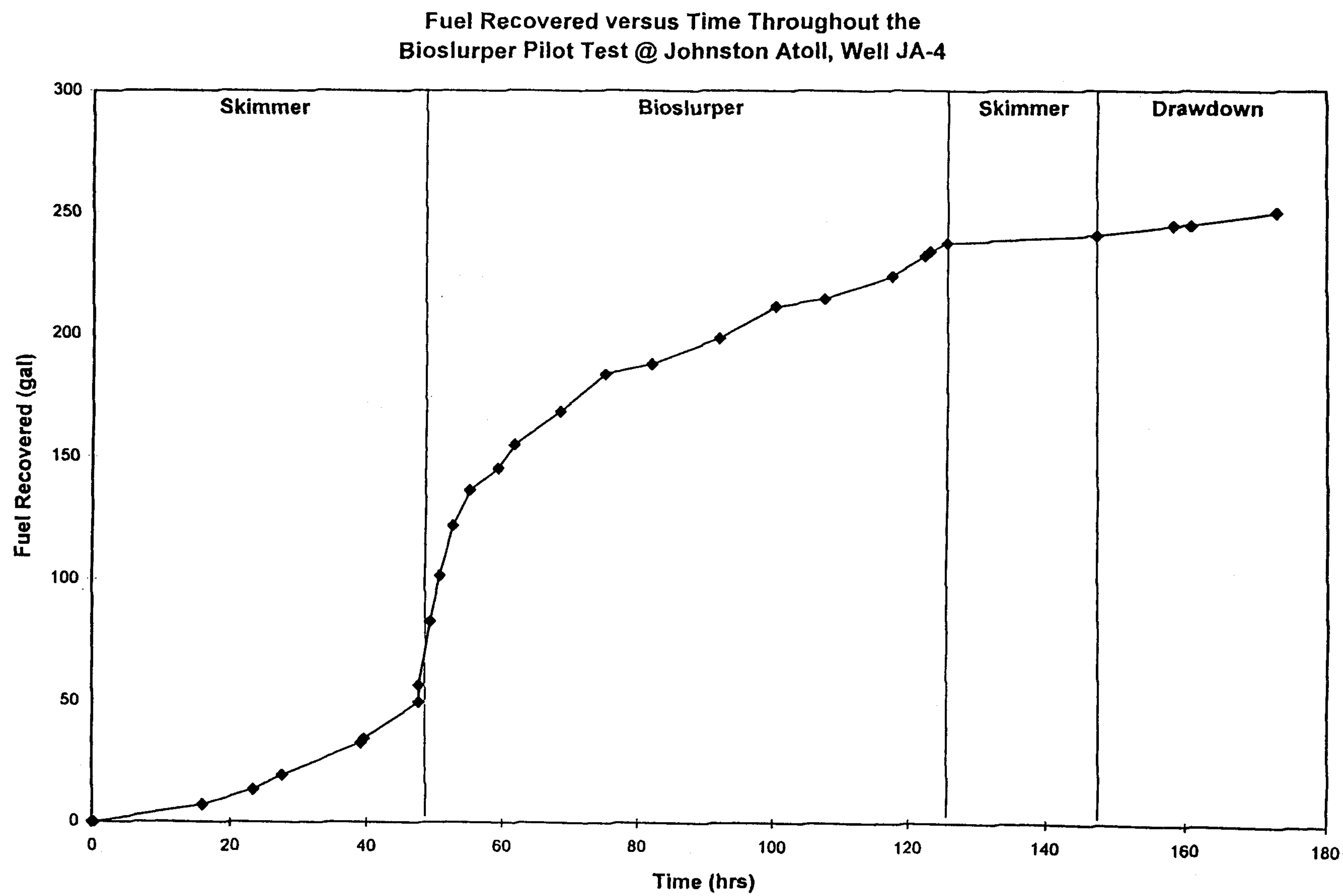

Figure 7. Fuel Recovery versus Time Throughout the Bioslurper Pilot Test @ Johnston Atoll, Well JA-4

Table 4. - Benzene and TPH Vapor Discharge Levels at 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	Jet Fuel	10	0.60	975	0.0017	5.7
Travis AFB	Jet Fuel	20	100	10,800	0.58	130
Wright-Patterson AFB	Jet Fuel	3.0	ND	595	0	1.0

ND = not detected.

Treatment of discharged groundwater generally is also required. At many sites it is possible to discharge separated groundwater directly to the sanitary sewer. At sites where the LNAPL is a low-volatility fuel, treatment for oil/water emulsions usually is necessary. Several options are available, all of which involve some level of physical separation. Using large pore bag filters (100 to 200 micron) and additional holding tanks to increase the residence time for the aqueous wastestream have been most successful. The use of surface-modified clay has also given positive results to reduce total petroleum hydrocarbon concentrations from the 100 to 150 ppm range to less than 25 ppm for discharge to the sanitary sewer. However, this option is not useful for treatment of benzene, toluene, ethylbenzene, and xylenes (BTEX).

SUMMARY

Data collected to date on the AFCEE Bioslurper Initiative indicate a dramatic increase in LNAPL recovery rates due to vacuum-enhanced extraction using dewatering technology (bioslurping). Bioslurping has also been demonstrated to enhance natural biodegradation through forced aeration (bioventing) as indicated in Table 2.

The Air Force Bioslurper Initiative is designed to assess the field application of the bioslurping technology at multiple Air Force sites. Data from the Bioslurper Initiative will be used to evaluate the feasibility of bioslurping in comparison to conventional technologies. In addition, Site Characterization data will be evaluated to determine which site parameters aid in determining the potential feasibility of bioslurping at a specific site.

The technical approach for conducting the bioslurper pilot tests includes assessing the geologic and hydrologic characteristics of each site, free-product baildown testing in site monitoring wells, soil gas analysis, and a bioslurper pump test. Bioslurping free-product recovery efficiency is compared to conventional skimming and dual-pump free-product recovery technologies. Bioventing potential is assessed via in situ respiration testing. Preliminary results to date demonstrate that bioslurping shows higher free-product recovery rates than conventional technologies. In some instances, recovery rates during bioslurping are an order of magnitude higher than with conventional technologies. These results indicate the potential feasibility of bioslurping as an alternative LNAPL recovery technology.

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