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CASE STUDY REPORT

FOR

OPTIMIZATION OF BIOSLURPER SYSTEM AT NAVAL WEAPONS STATION EARLE COLTS NECK, NEW JERSEY

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ACRONYMS AND ABBREVIATIONS

ALS	air/liquid separator
BDAT	best demonstrated available technology
bgs	below ground surface
BTEX	benzene, toluene, ethylbenzene, and xylenes
CEA	Classification Exception Area
COC	contaminant of concern
DAF	dissolved air flotation
GAC	granular activated carbon
gpd	gallons per day
gpm	gallons per minute
GQS	Groundwater Quality Standard
hp	horsepower
LIF	laser-induced fluorescence
LNAPL	light, nonaqueous-phase liquid
LRP	liquid ring pump
MW	monitoring well
ND	not detected
NJAC	New Jersey Administrative Code
NJDEP	New Jersey Department of Environmental Protection
NS	not sampled
NWS	Naval Weapons Station
O&M	operations and maintenance
OWS	oil/water separator
PAH	polycyclic aromatic hydrocarbon
ppm	parts per million
PVC	polyvinyl chloride
RI	Remedial Investigation
ROICC	Resident Officer in Charge of Construction
SCAPS	Site Characterization and Analysis Penetrometer System
SG	specific gravity
TPH	total petroleum hydrocarbon(s)
TVO	total volatile organic
UST	underground storage tank

EXECUTIVE SUMMARY

Naval Weapons Station (NWS) Earle is located in the town of Colts Neck, in east-central New Jersey. The objective of this project is to provide recommendations for optimizing the operation of the bioslurper system (Units #1 and #2) and site closeout at Site 16F. These recommendations are based on review of the design and operation documents for the site and on an observation of the system and site conditions made during a site visit. The scope of this project includes an overview of the design and installation of the current system; an evaluation of the operation and performance of the full-scale bioslurper system; and recommendations for exit strategies, system optimization, effluent treatment, and monitoring. An analysis of the costs of implementing the recommended changes also is included. Recommendations are specific to the bioslurper system at NWS Earle, but the general recommendations may be extended to bioslurper systems at other sites.

Site 16F, located in the north-central portion of NWS Earle, consists of several areas that contain fuel-related contaminants. These areas include a light, nonaqueous-phase liquid (LNAPL) plume southeast of Building C-16, an LNAPL plume northwest of Building C-50, and a former gas station near Building C-17. The LNAPL plume adjacent to Building C-16 is suspected to have been caused by a leaking underground diesel fuel transfer line which led from an underground storage tank (UST) at the northwest corner of Building C-18 to a fuel dispenser located between the railroad tracks north of C-50. The leak was detected in 1977, and the use of the transfer line was discontinued. As of 1997, this transfer line was still in place. Air samples from bioslurper Unit #1 indicate that some residual gasoline contamination also may be associated with this plume, perhaps due to releases from the former gas station. The plume at Building C-50 is reported to be the result of minor spills at the former diesel dispensing station.

The document review and the site visit revealed several factors that reduce the effectiveness of the bioslurper systems at Site 16F. These factors include:

- Cost of the aqueous effluent treatment system
- Restricted hours of operation
- Inadequate extraction well network.

Several recommendations to optimize the bioslurper system have been made based on the evaluation of site-specific data and experience with the bioslurping technology at other sites. Battelle has made several recommendations to optimize the systems at Site 16F. The first recommendation is the installation of additional wells to gain a better understanding of the extent of the LNAPL plume. The plume is poorly-delineated, and the bioslurper status reports reviewed by Battelle indicate that the current extraction network does not adequately cover the LNAPL plume. In addition, these wells should be used to improve the recovery of LNAPL. Other recommendations include adjusting the placement of the drop tube, replacing the oil/water separator, monitoring and possibly discontinuing off-gas treatment, reprogramming the alarm system, adding anti-scaling compound to the heat exchangers, and collecting aqueous effluent treatability data.

Upon implementing these recommendations, the system should be operated continuously. System performance and operating costs may then be evaluated further. Additional system modifications and/or operational procedures may be implemented based on revised cost and performance data. A flow chart for bioslurper system optimization and site closure at Site 16F is included with the recommendations in Section 4.0 of this report.

Section 1.0: INTRODUCTION

1.1 Project Objectives and Scope

The objective of this project is to develop recommendations for optimizing bioslurper system operations and site closeout at Site 16F, Naval Weapons Station (NWS) Earle, Colts Neck, NJ. These recommendations are based on a review of the design and operation documents for the site and on an observation of the system and site conditions made during a site visit. The scope of this project includes an evaluation of the operation and performance of the current bioslurper system, including recommendations for methods of system optimization, effluent treatment, and location of extraction wells. An exit strategy for the bioslurper system and a life-cycle cost analysis also are included. Recommendations are specific to the bioslurper system at NWS Earle, but the general recommendations may be extended to bioslurper systems at other sites.

1.2 Site Description

NWS Earle is located in the town of Colts Neck, in east-central New Jersey, approximately nine miles inland from the Atlantic Ocean (Figure 1). Site 16F is located in the north-central portion of NWS Earle, northeast of the intersection of Coral and Saipan roads, in an area currently used for industrial purposes. Bioslurper Unit #1 is adjacent to Building C-16, a shop building with power tools and a vehicle high-bay. Bioslurper Unit #2 is located to the north of Building C-50, which is used for railroad car maintenance. The area also contains multiple rail lines running north from Building C-50 and north and south to the east of Building C-16. A site map, including building numbers, streets, rail lines, and the locations of the bioslurper systems and extraction wells, is displayed as Figure 2.

1.3 Geology and Hydrogeology

According to regional maps, surface sediments at Site 16F consist of the Vincentown Formation and upper colluvium. The Vincentown Formation is described as a gray and green fine- to coarse-grained glauconitic sand with silt, and the upper colluvium consists of a shallow massive sand and silty sand (Foster Wheeler, 1999a). Boring logs and Site Characterization and Analysis Penetrometer System (SCAPS) data indicate that the soil underlying Site 16F consists of fine- to medium-grained sand and silty sand. Relief at the site is minimal, with the drainage channels between the railroad tracks being the most significant local differences in surface elevation.

Groundwater at the site occurs in the shallow unconfined aquifer consisting of the upper colluvium and the Vincentown Formation. Monitoring of the wells at Site 16F indicates that the groundwater occurs 6 to 10 ft below the land surface. Water table elevations vary seasonally within this range. Slug testing performed during the Remedial Investigation (RI) indicate that the hydraulic conductivity at the site is approximately 1 ft/day, which is approximately 1/3 of the average value for the upper colluvium and Vincentown Formation (Brown and Root Environmental, 1996). Water table elevations measured during the RI and during the operation of the bioslurper system indicate a northerly groundwater flow direction, with some localized flow to the west/northwest near Building C-16 (Foster Wheeler, 1999a).

1.4 Contamination Description

Site 16F consists of several areas that contain fuel-related contaminants. These areas include a light, nonaqueous-phase liquid (LNAPL) plume southeast of Building C-16, an LNAPL plume northwest of Building C-50, and a former gas station near Building C-17 (Foster Wheeler, 1997)

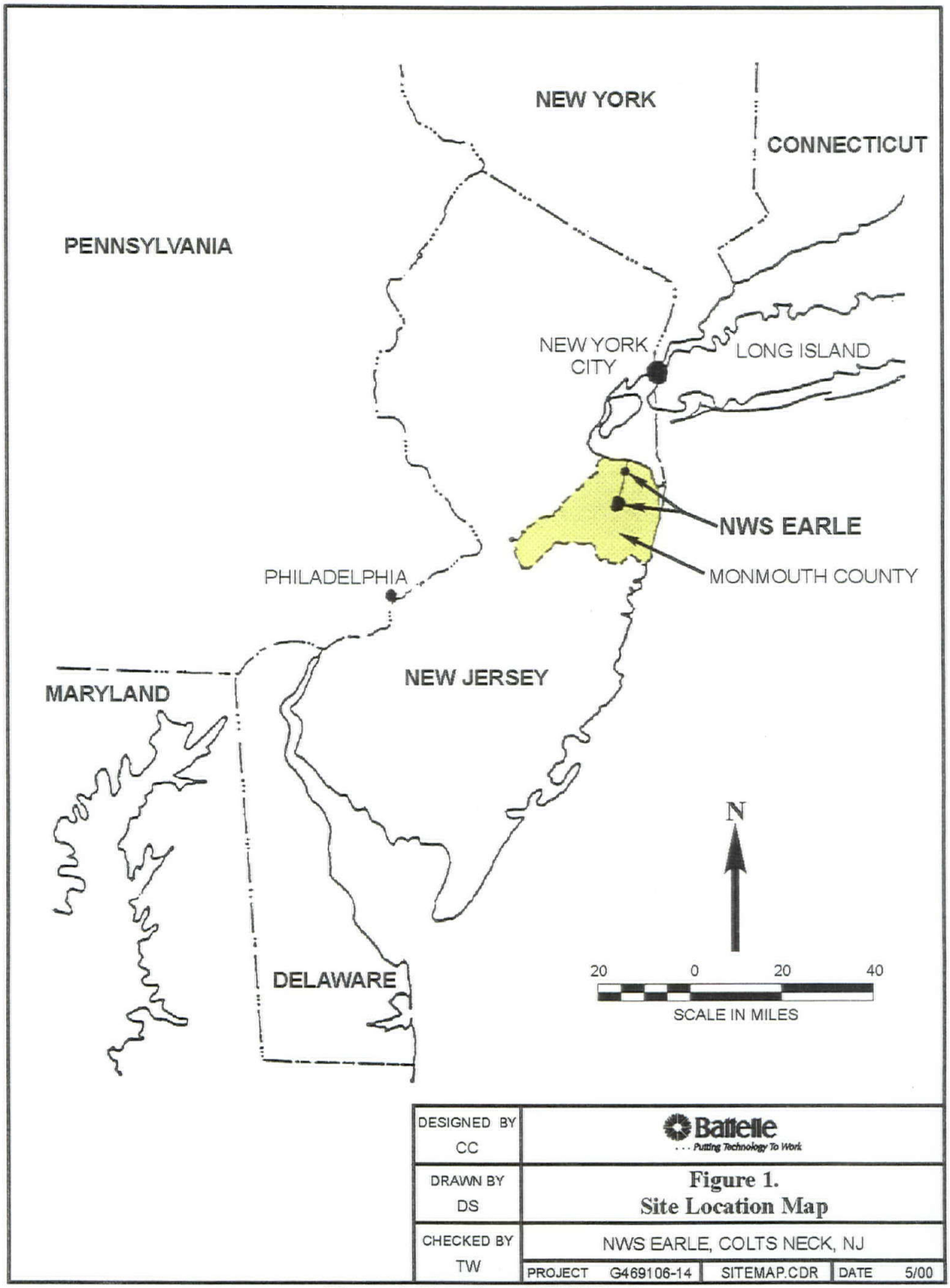


Figure 1. Location of NWS Earle

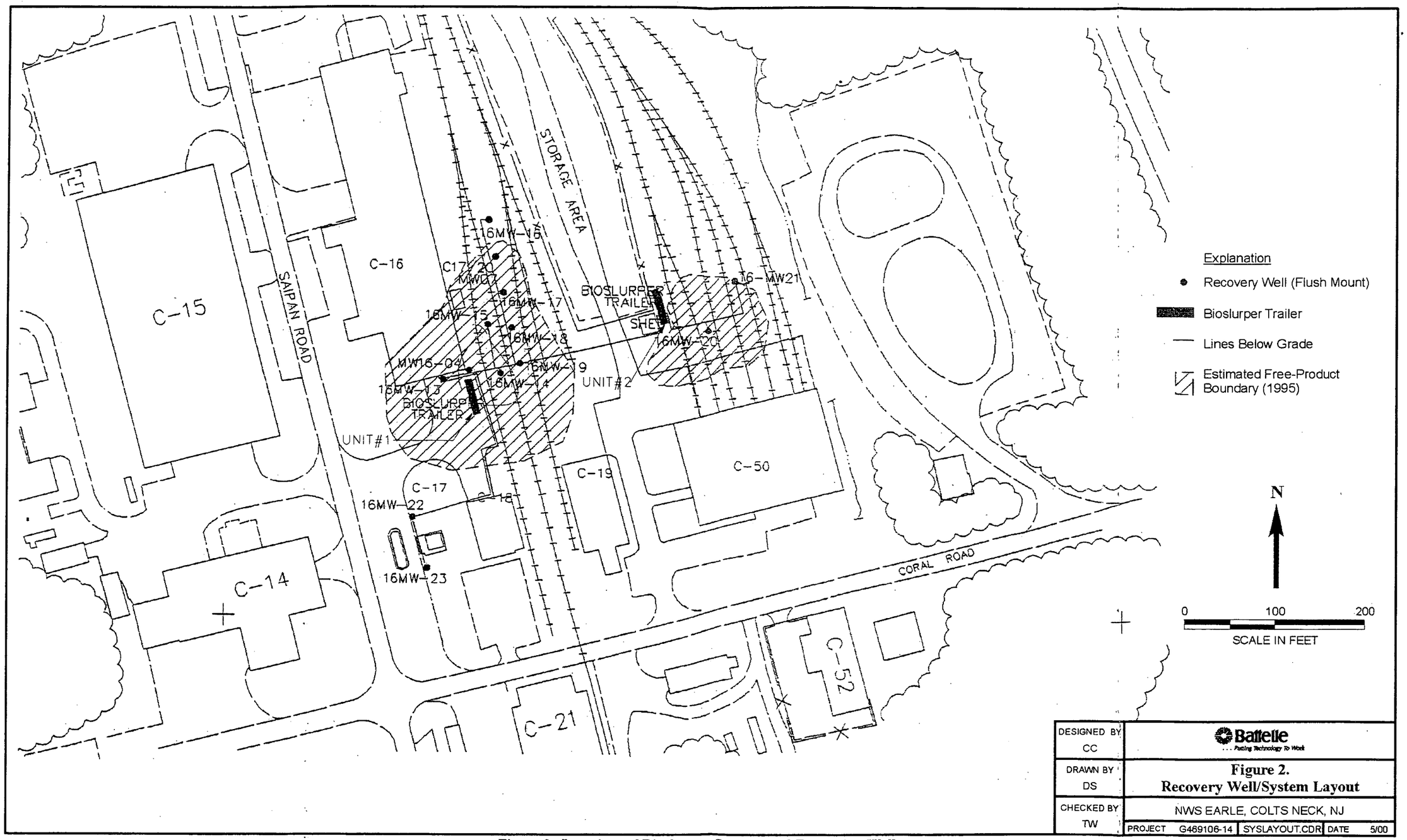


Figure 2. Locations of Bioslurper Systems and Extraction Wells

(Figure 3). The LNAPL plume adjacent to Building C-16 is suspected to have been caused by a leaking underground diesel fuel transfer line which led from an underground storage tank (UST) at the northwest corner of Building C-18 to a fuel dispenser located between the railroad tracks north of C-50. The leak was detected in 1977, and the use of the transfer line was discontinued. As of 1997, this transfer line was still in place (Foster Wheeler, 1997). Air samples from Unit #1 indicate that some residual gasoline contamination also may be associated with this plume, perhaps due to releases from the former gas station. The plume at Building C-50 is reported to be the result of minor spills at the former diesel dispensing station (Foster Wheeler, 1999a).

Several soil borings were completed as part of a site investigation in 1992. Five borings were installed to the water table, and a soil sample was collected from each boring at approximately 8 ft below ground surface (bgs), between the water table and the depth of the transfer line. Elevated total petroleum hydrocarbon (TPH) concentrations were detected in all of the samples, ranging from 4,700 to 22,000 mg/kg. A geophysical survey indicated the presence of several buried pipes (Foster Wheeler, 1997).

Additional sampling was performed during an RI conducted in 1995 by Brown and Root Environmental (1996). This investigation demonstrated that groundwater at Site 16F had been impacted by the hydrocarbon contamination in the subsurface. Monitoring wells installed during the RI contained up to 2 ft of LNAPL (Foster Wheeler, 1997). The LNAPL and contaminated soil act as sources of hydrocarbon contamination to the groundwater.

SCAPS investigations were conducted by the Navy in 1995 and covered the areas between Buildings C-17 and C-18 and north of C-50. The SCAPS uses laser-induced fluorescence (LIF) to detect the presence of polycyclic aromatic hydrocarbons (PAHs) in the subsurface. Brown and Root Environmental conducted further direct-push and LIF investigations at the site in 1996 (Foster Wheeler, 1997). The area depicted as the extent of the LNAPL plume on maps created by Foster Wheeler was based on the 1995 SCAPS results. The extent of the fuel-impacted areas interpreted by Foster Wheeler based on these studies is shown in Figure 3. However, the plume extent estimated by Foster Wheeler appears to be slightly larger than the area where the SCAPS results indicated the potential presence of LNAPL. The extent of LNAPL contamination according to the SCAPS investigation is included as Figure 4 (Foster Wheeler, 1999a).

While preparing this report, Battelle created contour plots of the LNAPL plume at Site 16F using depth-to-LNAPL/groundwater data provided by Foster Wheeler. Contouring software (Surfer™) was used to estimate the extent of the LNAPL plumes based on the thickness of the LNAPL layers present in the few existing monitoring wells. Due to the small number of monitoring wells, the area of the plume can be only roughly estimated. The need for improved delineation of the plume is discussed in Section 3.2. The Surfer™ plots created by Battelle are included as Figures 5 and 6.

The distribution of the dissolved contaminant plume is monitored outside of the LNAPL removal effort. Dissolved hydrocarbons (benzene, toluene, ethylbenzene, xylenes [BTEX], and naphthalene) concentrations are monitored in eight wells at Site 16F. Dissolved hydrocarbons have been observed in several of the monitoring wells. The groundwater monitoring effort is described in greater detail in Section 3.7.

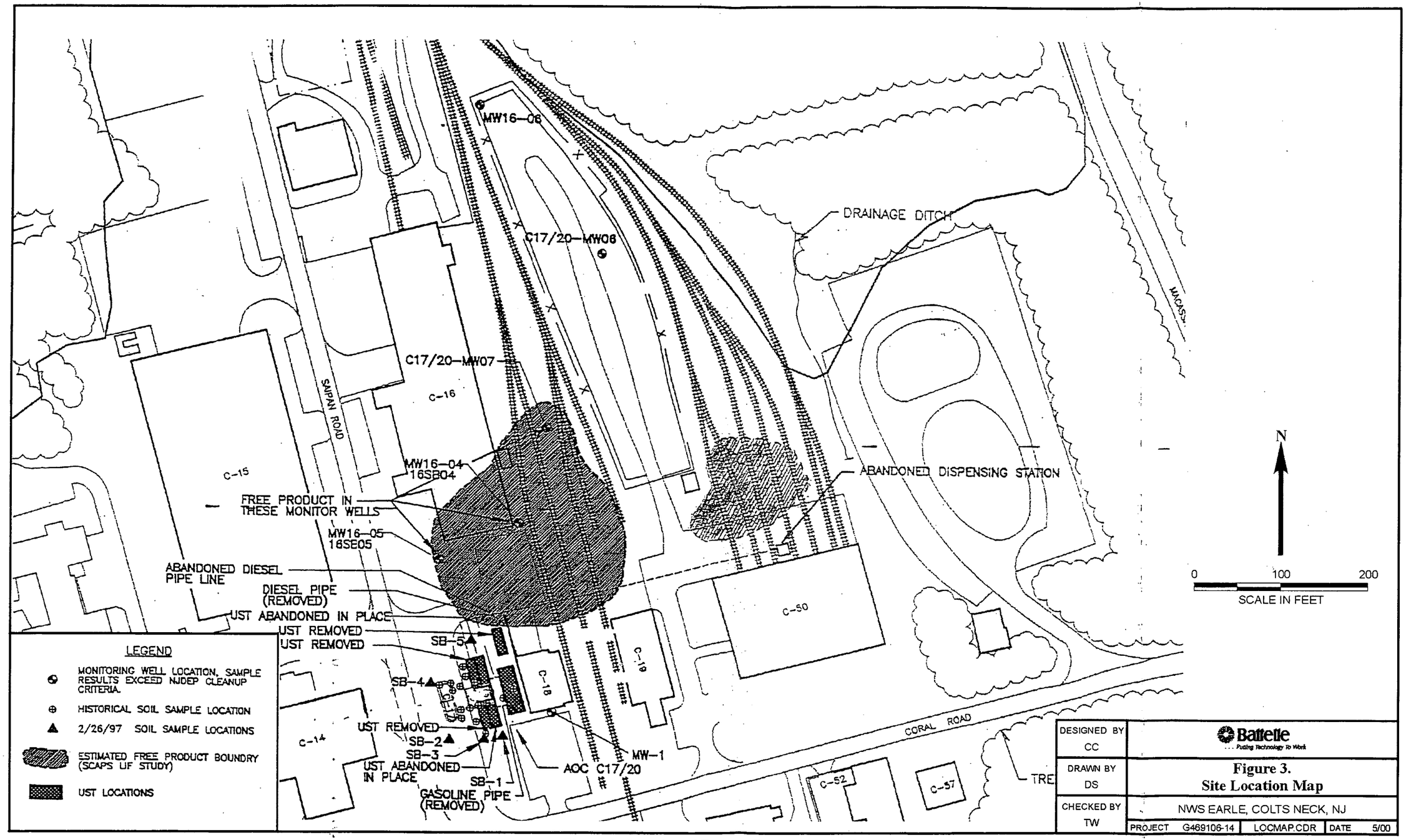


Figure 3. Location of Former Tanks and Pipelines

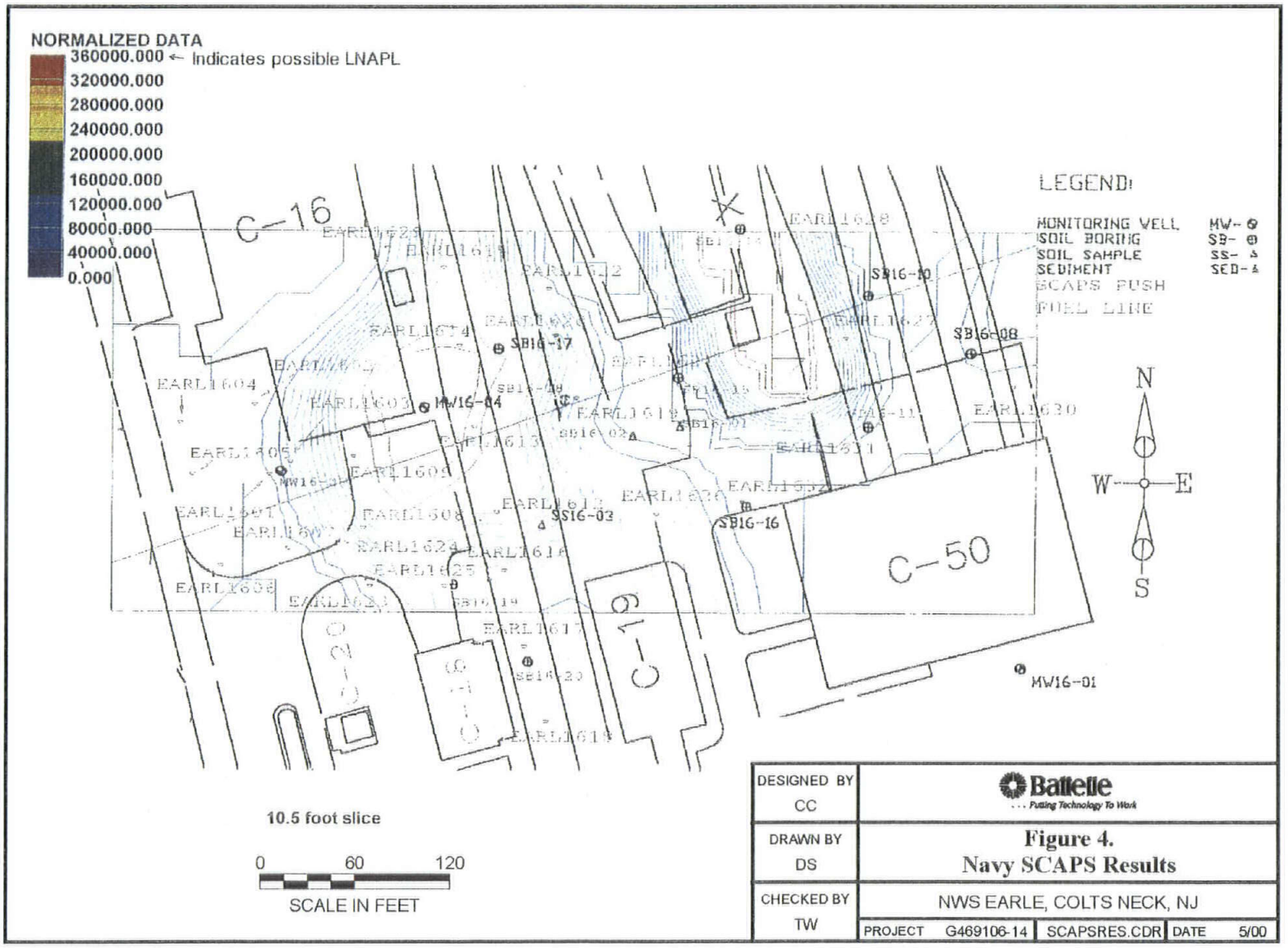


Figure 4. Navy SCAPS Results

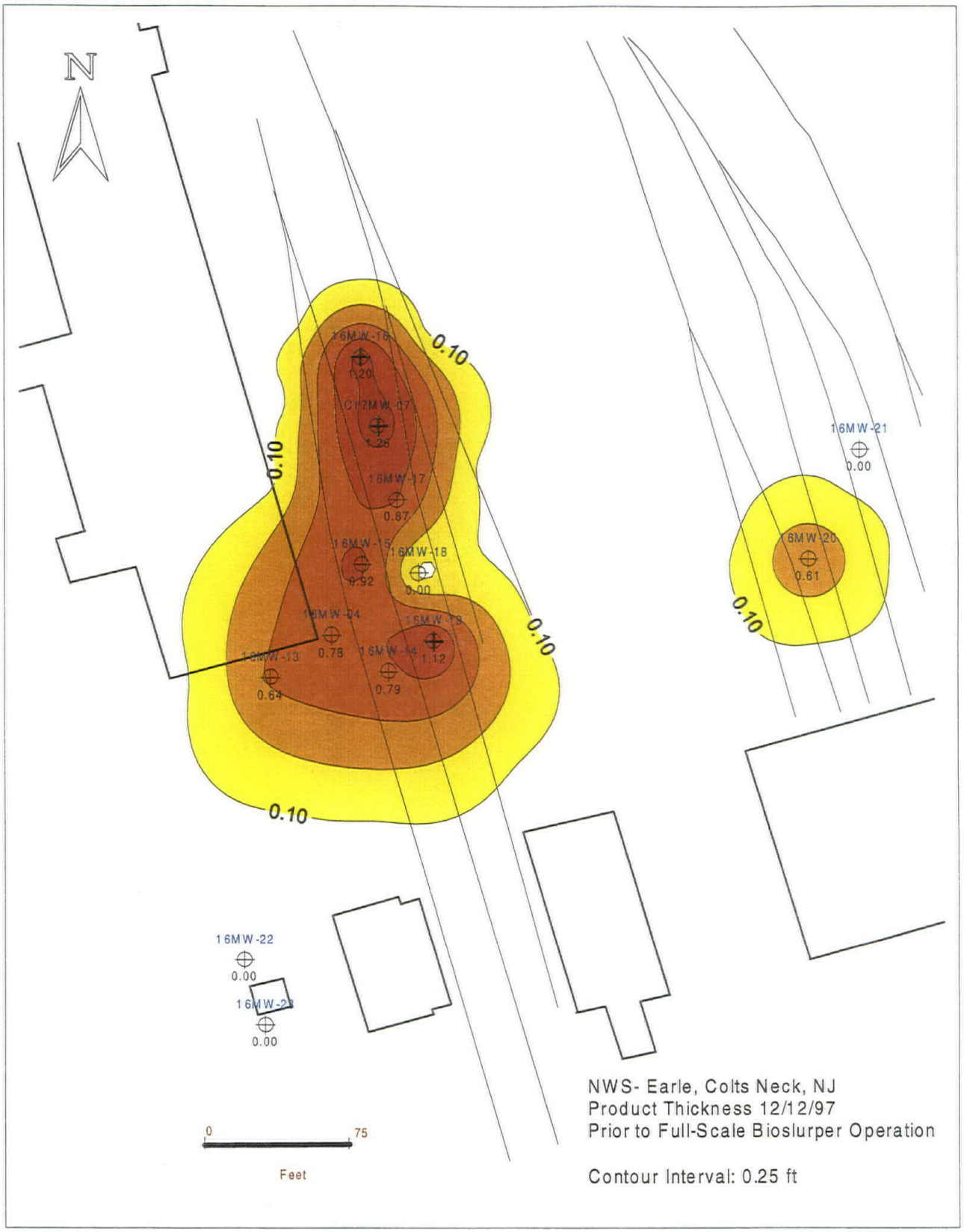


Figure 5. Product Thickness Isopleth 12/12/97

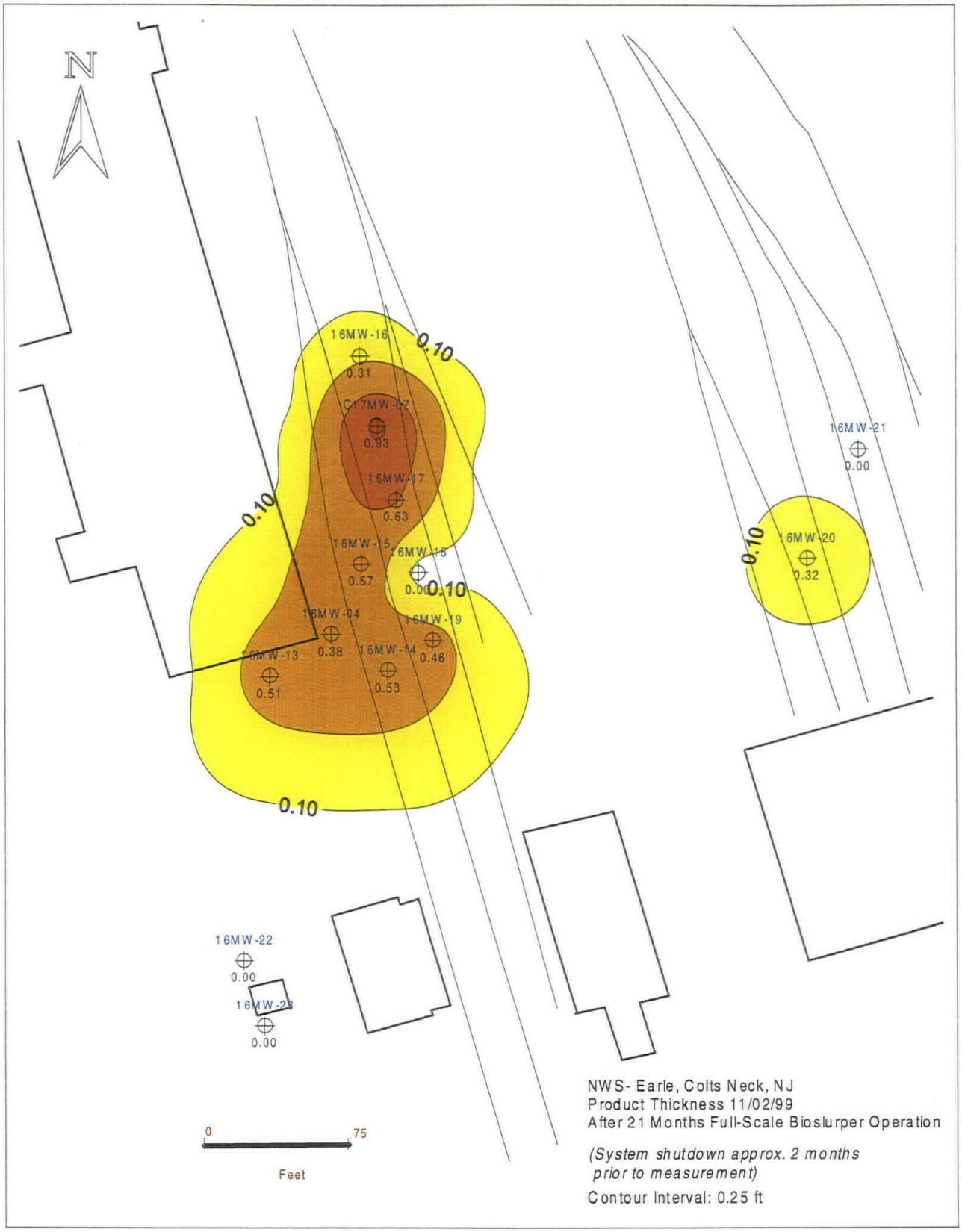


Figure 6. Product Thickness Isopleth 11/02/99

1.5 Fate and Transport of LNAPL and Dissolved Hydrocarbons

Analytical fate and transport modeling has not been performed for Site 16F. Measurements at monitoring wells indicate a northerly flow of groundwater, which could potentially transport contaminants in that direction. The area immediately downgradient of the source area (according to measurements collected in 1998 and 1999 by Foster Wheeler [1999a]) is characterized by similar industrial-type structures and a great deal of open ground covered only by railroad lines. Building C-16, which at a minimum appears to be in the path of the contamination and which may overlie a portion of the LNAPL plume, is scheduled for demolition by the end of calendar year 2000 (Goepfert, 2000).

1.6 Regulatory Perspectives of Source Removal

The New Jersey Department of Environmental Protection (NJDEP) requires removal of free product, regardless of any site-specific risks caused by the free product. The UST section of the New Jersey Administrative Code (NJAC 7:14B) requires that the owner of a UST that has discharged hazardous substances (including petroleum products as listed in Appendix A of NJAC 7:1E) must perform a remedial action in accordance with NJAC 7:26E-6. The following is a key requirement of this regulation (underline added):

> NJAC 7:26E-6.1(d): "Free and/or residual product determined to be present pursuant to NJAC 7:26E-2.1(a)11 shall be treated or removed when practicable, or contained when treatment or removal are not practicable. Likewise, natural ground water remediation for dissolved phase contamination may be implemented if it is determined by the Department that active ground water remediation for the dissolved phase is impracticable or not cost-effective. Decisions regarding the practicability of a remedial decision shall be made by the Department on a case by case basis. Natural remediation of free and/or residual product will not be allowed."

Based on these regulations, free product recovery can be terminated when free product is no longer present or when free product removal is no longer practicable. When free product recovery is completed, then the groundwater and soil may require further action.

1.7 Remedial Action

The results of previous investigations at Site 16F, including the RI, demonstrated the presence of LNAPL on the water table. Foster Wheeler performed a brief, one-day pilot test comparing bioslurping to passive skimming. During this test, the passive skimming system recovered approximately 10 gallons of LNAPL, whereas the bioslurper system recovered approximately 100 gallons (Heffron, 2000). The one-day skimming/bioslurping comparison test was not described in any of the documents provided to Battelle, including the Draft Evaluation Report for the pilot test (Foster Wheeler, 1996). Based on this test and literature reporting a superior LNAPL recovery rate for bioslurping as compared to other technologies, bioslurping was selected as the remedial technology to recover LNAPL at Site 16F. Foster Wheeler then conducted a long-term pilot study to evaluate the performance of the bioslurper system over a three-month period (Foster Wheeler, 1996). Based on the results of the pilot study, Foster Wheeler concluded in the Draft Evaluation Report that "bioslurping is a feasible remedial technology for the site" (Foster Wheeler, 1996). The report goes on to state that the problem of the high iron content in the groundwater and the extent of the LNAPL plume should be addressed prior to the full-scale design.

The final work plan detailing the installation and operation of the system was completed in July 1997 (Foster Wheeler, 1997). Design specifications and operation, maintenance, and monitoring procedures are included in the operations and maintenance (O&M) manual for the site (Foster Wheeler, 2000).

Section 2.0: DESIGN AND INSTALLATION OVERVIEW

Installation of the full-scale bioslurper system was completed in January 1998 (Foster Wheeler, 1998a). The system includes two self-contained bioslurper units, each housed in its own cargo container for protection from the elements. Each bioslurper consists of liquid extraction, process, and treatment units. Each extraction system is connected to the wells by a manifold system. A vapor treatment system was installed with Unit #1. Vapor from Unit #2 is discharged directly to the atmosphere. Aqueous effluent from each system is treated and discharged to the Base sanitary sewer system. Both systems include safety controls and alarms, and may be started and shut down by remote control (Foster Wheeler, 1999a).

2.1 Extraction Wells

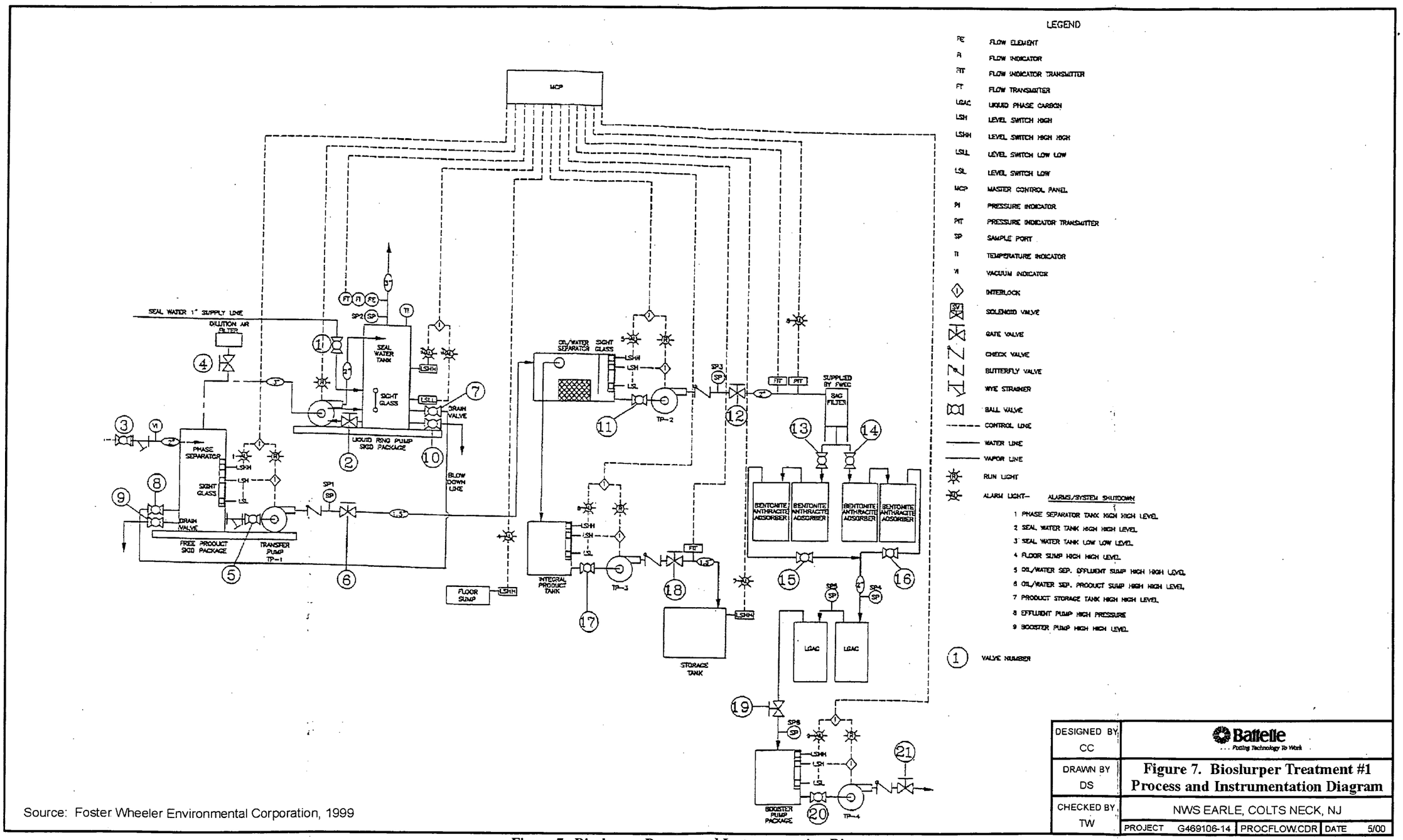
Nine extraction wells were installed for the full-scale bioslurper system, in addition to two existing wells. Two other wells were installed for bioventing. The new wells were installed using a drill rig equipped with a hollow-stem auger to a depth of approximately 20 ft bgs. The wells were constructed of 4-inch-diameter schedule 40 polyvinyl chloride (PVC), with 15 ft of 0.010-inch-slotted screen. All wells were completed in flushmount steel vaults.

The locations of the extraction wells (Figure 2) were determined using the results of the SCAPS investigation, existing LNAPL thickness measurements, and the general groundwater flow direction. These wells were installed under the assumption that additional wells may be required to complete the LNAPL removal (Foster Wheeler, 1999a). Two of the new wells, 16MW-20 and 16MW-21, were installed in the plume north of Building C-50. These wells are spaced approximately 60 ft apart. Wells within the contaminated area adjacent to Building C-16 are spaced closer together, approximately 35 to 40 ft apart. Well spacing in each cluster is partially controlled by the presence of buildings and railroad lines, which makes a set grid pattern of well spacings difficult to achieve.

The wells are connected to the extraction and treatment system by a pipe manifold. The manifold was constructed of 2-inch-diameter schedule 40 PVC pipe, and was enclosed within 4-inch-diameter schedule 80 PVC pipe. The outer pipe is designed to serve as secondary containment. The entire manifold was installed subgrade. Either bioslurper unit may be used to extract from wells located between the railroad tracks (Foster Wheeler, 1999a).

2.2 Extraction Pump and Associated Equipment

The remediation system at Site 16F consists of two fully enclosed bioslurper systems (Unit #1 and Unit #2) that contain components for extraction and treatment of LNAPL, groundwater, and soil vapor. The two bioslurper units are identical with two exceptions: Unit #1 includes a vapor treatment unit, which is housed in an adjacent shed; and Unit #2 includes an effluent sump and a booster pump, which are used to transfer the aqueous waste to the sewer inlet adjacent to Unit #1. Except for these differences, the following description of the bioslurper system applies to both units. A process instrumentation diagram of Unit #1 is included as Figure 7. The liquid ring pump (LRP) produces the vacuum that draws the LNAPL, groundwater, and soil vapor through the subsurface, into the extraction wells, up the drop tubes, through the manifold, and into the bioslurper units. Inside the enclosure, the process stream is pulled into a knock-out tank, which captures the recovered LNAPL and groundwater. The recovered soil vapor is pulled through the LRP and discharged into an air/liquid separator (ALS). The vapor then flows out the stack of the ALS, to the atmosphere at Unit #2 and to carbon treatment at Unit #1. The recovered liquids are pumped from the knock-out tank to an oil/water separator (OWS) and other water treatment units prior to discharge to the Base sanitary sewer.



Source: Foster Wheeler Environmental Corporation, 1999

DESIGNED BY CC	Battelle ... Putting Technology To Work
DRAWN BY DS	**Figure 7. Bioslurper Treatment #1 Process and Instrumentation Diagram**
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Figure 7. Bioslurper Process and Instrumentation Diagram

2.2.1 Liquid Ring Pump. Each unit is equipped with a 7.5-horsepower (hp) LRP. The LRP is coupled to a 120-gallon vertical pressure cylinder, which serves as an ALS and as a source of seal water to the LRP. Seal water flowing from the ALS to the LRP passes through a heat exchanger. The purpose of the heat exchanger is to lower the temperature of the seal water, because elevated seal water temperatures can have a detrimental effect on the vacuum produced by the LRP. The LRP is equipped with a variety of sensors and switches that cause it to shut down under off-normal conditions. The ALS also has high-high and low-low liquid level switches to shut down the LRP.

The ALS associated with the LRP receives seal water from a water line in Building C-16. The use of this outside seal water supply eliminates the problems sometimes associated with using recovered groundwater for seal water supply, including scaling of the LRP head and mixing of the recovered LNAPL and groundwater in the pump head. This ALS also serves to capture water droplets entrained in the vapor flow to the vapor treatment unit (Unit #1). The ALS has a de-mister pad that allows the water droplets to fall back into the tank rather than be pulled by the blower into the carbon units.

2.2.2 Knock-Out Tank. The knock-out tank is a 120-gallon vertical pressure cylinder, similar to the ALS. The LRP pulls the multi-phase process stream into the bioslurper enclosure and into the knock-out tank, where the recovered LNAPL and groundwater are captured. The LRP also pulls the vapor from the top of the knock-out tank into the ALS, where it then is discharged through the ALS stack. The captured liquids are pumped into an OWS by a progressive cavity transfer pump. (The progressive cavity pump was selected because it is designed to create less mixing of LNAPL and water than other pump designs.) The transfer pump cycle is controlled by liquid level switches located in a sight tube. The sight tube also includes a high-high level switch to shut down the bioslurper in the event that the liquid level in the tank rises to a predetermined mark.

2.3 Water Treatment

Water treatment consists of first separating the water and LNAPL, and then treating the water to meet discharge standards for dissolved contaminants. Water treatment consists of oil/water separation, solids filtration, hydrophobic clay treatment to remove emulsified oil, and granular activated carbon (GAC) treatment to remove dissolved hydrocarbons.

2.3.1 Oil/Water Separator. Recovered LNAPL and groundwater are pumped together into the inlet of the OWS. The OWS is a gravity-driven unit rated for a flowrate of 120 gallons per minute (gpm), which is approximately one order of magnitude greater than the typical flowrate for this system. The larger size allows additional residence time for phase separation. Droplets of oil coalesce on a submerged hydrophobic packing media and float to the surface when they reach sufficient size. The floating LNAPL flows into an adjustable skimmer tube located at the liquid surface and then into an integrated 100-gallon LNAPL holding compartment. When the LNAPL in the holding compartment reaches a preset level, a level switch activates a 1-hp pump, which transfers the LNAPL to a 275-gallon holding tank.

Water flows through the OWS and into an integrated 200-gallon sump compartment. A level switch in the sump compartment activates a 5-hp pump, which transfers the water through a bag filter and then through the clay/carbon treatment units.

2.3.2 Bag Filter. The bag filter is an intermediate step between the OWS and the clay/carbon units. The bag filter consists of a 100-micron mesh filter enclosed in a steel cylinder, and traps suspended solids so that they do not accumulate in the clay units. The unit is rated for 20 gpm of flow. A pressure gauge is mounted on the outside of the cylinder to indicate when the filter is clogging and should be replaced.

2.3.3 Clay and Carbon Units. The clay and carbon units are the final phase of water treatment prior to discharge to the Base sanitary sewer. After passing through the bag filter, the water flows through three canisters of clay (300-lb clay each) and two of GAC (300-lb carbon each) placed in series. The clay units consist of a special mixture of chemically modified clay and anthracite filtration media, rated to absorb up to 60% of its weight in oil and grease (Foster Wheeler, 1997). Removing oil and grease from the effluent stream prior to the GAC units is critical, because the presence of LNAPL or oil and grease constituents accelerates the consumption of GAC.

2.4 Vapor Treatment

Vapor treatment is used only to treat the off-gas from Unit #1. A vapor treatment system is installed in a shed adjacent to the Unit #1 bioslurper. Vapor flows from the discharge stack of the ALS/seal water tank associated with the LRP through a pipe and into the vapor treatment shed. Upon reaching the shed, the vapor stream enters a 120-gallon moisture separator. The moisture separator is equipped with a de-mister to remove the liquids from the stream. When sufficient liquid accumulates in the moisture separator, a solenoid valve is opened, allowing the separator to be drained by the vacuum of the LRP into the knock-out tank in Unit #1. The vapor continues into a pair of 180-lb canisters of vapor-phase GAC, plumbed in series. The treated vapors then are discharged to the atmosphere (Foster Wheeler, 1999a).

2.5 System Controls and Alarms

The bioslurper systems are equipped with a variety of control and alarm switches, all of which are tied into a master control panel. In general, high- and low-level switches activate transfer pumps, and high-high and low-low switches turn on alarms and turn off the bioslurper system. Alarm switches are included in every tank that could potentially release LNAPL or contaminated water in the event of an overflow. Activation of any of the following switches will turn off the entire bioslurper system (Foster Wheeler, 1999a):

- High-high sensor in the knock-out tank
- High-high and low-low sensors in the ALS/seal water tank
- High-high sensor in the OWS LNAPL storage compartment
- High-high sensor in the OWS effluent sump compartment
- High-level sensor in the LNAPL storage tank
- High-high sensor in the booster pump transfer tank at Unit #2
- High-high sensor in the vapor treatment system moisture separator at Unit #1
- High-pressure switch in the aqueous effluent treatment canisters
- High-level sensor in a floor sump within the treatment container.

In the event of a system shutdown, the master control panel sends a message via fax and/or pager to Foster Wheeler, the NWS Earle Resident Officer in Charge of Construction (ROICC), the NWS Earle Fire Department, and Naval Facilities Engineering Command Northern Division (Foster Wheeler, 1999a; Heffron, 2000). The system may be restarted remotely by Foster Wheeler; however, the cause of the shutdown must be identified and corrected before the system is restarted.

Section 3.0 FULL-SCALE SYSTEM EVALUATION

To evaluate the bioslurper system installed at Site 16F, Battelle reviewed the following documents:

- *Final Work Plan for Bioslurping System at Naval Weapons Station Earle* (July 11, 1997)
- *Bioslurper Status Report for February and March 1998* (April 21, 1998)
- *Bioslurper Status Report for April through August 1998* (September 2, 1998)
- *Bioslurper Status Report for September through November 1998* (December 22, 1998)
- *Bioslurper Status Report for December 1998 through March 1999* (April 1999)
- *Draft One Year Operational Report for Site 16F Bioslurper Systems at NWS Earle* (July 16, 1999)
- *Bioslurper Status Report for August through November 1999* (December 15, 1999).

After the document review, Battelle made a site visit to examine the full-scale bioslurper system and interview personnel responsible for maintaining the operation of the system. After the site visit was completed, Battelle received the following additional documents:

- *Operations and Maintenance Manual for the Multi-Phase Extraction Systems (Bioslurpers) at Site 16F* (February 22, 2000) (received February 25, 2000)
- *Draft Evaluation Report for Bioslurping Pilot Study* (December 3, 1996) (received May 12, 2000)
- *Year 1 Groundwater Monitoring Report for Remedial Action Implementation, Buildings C-17/20/16/50* (August 1999) (received May 12, 2000).

Evaluation of the performance of the bioslurper system equipment and current operation practices are included in this section. Recommendations for improving operation of the system are included in Section 4.0.

3.1 Pilot Scale Testing

Vacuum-enhanced free product recovery is an in situ technology; hence, the remedial system must be designed to cope with subsurface heterogeneity and changing site conditions. To properly design a full-scale system, a pilot test must first be performed. Data that should be collected and reported should include, at a minimum:

- Free product recovery rate.
- System operating parameters including vacuums, temperatures, and flowrates.
- Multiple well extraction test data. Data from these tests should indicate how flowrates and system vacuums change as the number of wells used for extraction is increased.
- Vacuums at each extraction well during each test.
- Time-series free product and water table elevation measurements.
- Concentrations of TPH and any other contaminants of concern in off-gas and aqueous effluent from the bioslurper system.
- Specific gravity and viscosity of the LNAPL.
- Observations of the quality of the water in the OWS (i.e., presence of floating solids, color).
- Respiration test data.

In addition, it may be necessary to perform bench-scale treatability tests using the bioslurper process water in order to design a cost-effective water treatment system. These data are used to design a cost-effective full-scale vacuum-enhanced free product recovery system.

3.1.1 Pilot Test Activities. In 1996 at Site 16F, Foster Wheeler performed a brief, one-day pilot test comparing bioslurping to passive skimming. They then conducted a long-term pilot study to evaluate the performance of the bioslurper system over a three-month period (Foster Wheeler, 1996). Three soil-gas monitoring points (VW-01, -02, and -03) were installed radially outward at 10, 20, and 40 ft, respectively, from extraction well MW16-04. A piezometer also was installed at VW-01 to monitor LNAPL thickness.

A baildown test was performed at well MW16-04 on July 3, 1996. The initial product thickness in the well was 4.4 ft. From this test, Foster Wheeler estimated the LNAPL thickness to be 1.1 ft (Foster Wheeler, 1996). The Draft Evaluation Report states that the "true product thickness is estimated at the point where the water table begins to deflect due to the accumulation of product thickness" (Foster Wheeler, 1996). No details were included in that report on the amount or rate of LNAPL recovery into the well, or the precise method of calculating the estimated LNAPL thickness.

According to the text of the Draft Evaluation Report, the long-term pilot study began on July 22, 1996, and continued until October 25. The report indicates that the system operated for only 717 hours (approximately 30 days total) during this three-month period. The low operational time was due to electrical re-wiring (31 days) and various other system malfunctions due to iron fouling and other miscellaneous problems (Foster Wheeler, 1996). However, data sheets attached to the Draft Evaluation Report contradict the report text and indicate that system operation continued until approximately November 8, 1996, for an additional 30 hours beyond the total of 717 hours specified in the report.

According to the data sheets attached to the Draft Evaluation Report, the bioslurper recovered approximately 52,760 gal of groundwater and 134 gal of LNAPL during the pilot test. Over the course of the test, the average groundwater recovery rate was approximately 1.2 gpm, while the LNAPL recovery rate was approximately 4.3 gallons per day (gpd). The volume of LNAPL and groundwater recovered are plotted on Figures 8 and 9, respectively. Based on the analytical results of an aqueous sample collected on October 31, 1996, the report states that approximately 8 kg of hydrocarbons were removed from the 52,640 gal of groundwater recovered by the bioslurper to that date (Foster Wheeler, 1996). The mass of hydrocarbons recovered in the vapor phase was not included in the Draft Evaluation Report (Foster Wheeler, 1996). Analytical results were included in appendices to the Draft Evaluation Report, but these appendices were not included in the copy provided to Battelle. Vapor flowrate data also were not included in the report.

3.1.2 Conclusions Made by Foster Wheeler. Based on the final month of the study and the respiration test, Foster Wheeler concluded that a pressure radius of up to 40 ft could be achieved. No comparison of bioslurping to other LNAPL recovery techniques is described in the Pilot Test Report (Foster Wheeler, 1996). Foster Wheeler recommended that the high iron content in the recovered groundwater should be addressed in the design of the full-scale system. Additional investigation of the extent of the LNAPL plume also was recommended.

3.1.3 Evaluation of Pilot Test. Some of the data recommended for collection in Section 3.1 of this report were collected during the pilot test. Data collected and reported during the pilot test include LNAPL and groundwater recovery rates, observations of water quality, contaminant concentrations in aqueous and vapor effluents (listed in Draft Evaluation Report as Appendix C, but not included in the copy provided to Battelle), and respiration test data. Other important data recorded during the pilot test include operating time, baildown test data, and soil-gas concentrations and vacuums. However, several

sets of data important in the design of a full-scale bioslurper system were not collected during the pilot test. These include:

- Vapor discharge flowrate
- Pump-head vacuum and seal water temperatures
- Multiple well extraction test data (pilot test was performed on a single well)
- Vacuum at the extraction well
- Depth to LNAPL/groundwater measurements during system operation
- Specific gravity and viscosity of the LNAPL.

These data are required to design a cost-effective full-scale system. In addition, the basis for selecting the hydrophobic clay media and GAC media to treat the aqueous effluent is not apparent. Bench-scale treatability tests should be performed to determine the most cost-effective water treatment technology

3.2 Free Product Plume Delineation

In 1995, an investigation was conducted using the SCAPS system. The data were used to estimate the area of suspected free product (Figure 4). The presumed plume boundaries are not based on observations from extraction or monitoring wells; rather, the boundaries are based on based on concentrations of hydrocarbons in the soil. The SCAPS data and gradients calculated from LNAPL observed in existing wells currently indicate that the LNAPL plume extends to the south and west of the existing extraction wells near Building C-16.

Battelle plotted the oil thickness measurements collected from the bioslurper extraction wells using Surfer™ software to delineate the product plume (Figures 5 and 6). Figure 5 was generated using thickness data measured prior to beginning operation of the bioslurper system (January 15, 1998). Figure 6 was generated using data collected about 21 months after bioslurper treatment had been initiated. The system had been shut down about 2 months prior to when the measurements used to generate this figure were taken. It appears that the product thickness has decreased significantly during the first 2 years of system operation.

Additional wells are required to better delineate the product plume. The boundaries of the product plume may change considerably as data from new wells becomes available. Foster Wheeler (1999a) has proposed that two additional extraction wells and an additional monitoring well be installed in the vicinity of the building. One of these proposed extraction wells would be located inside the building, and the other would be located along the east side. The proposed monitoring well would be located immediately west of Building C-16. Recommendations for installing additional wells for plume delineation and potential LNAPL extraction are included in Section 4.2.1.

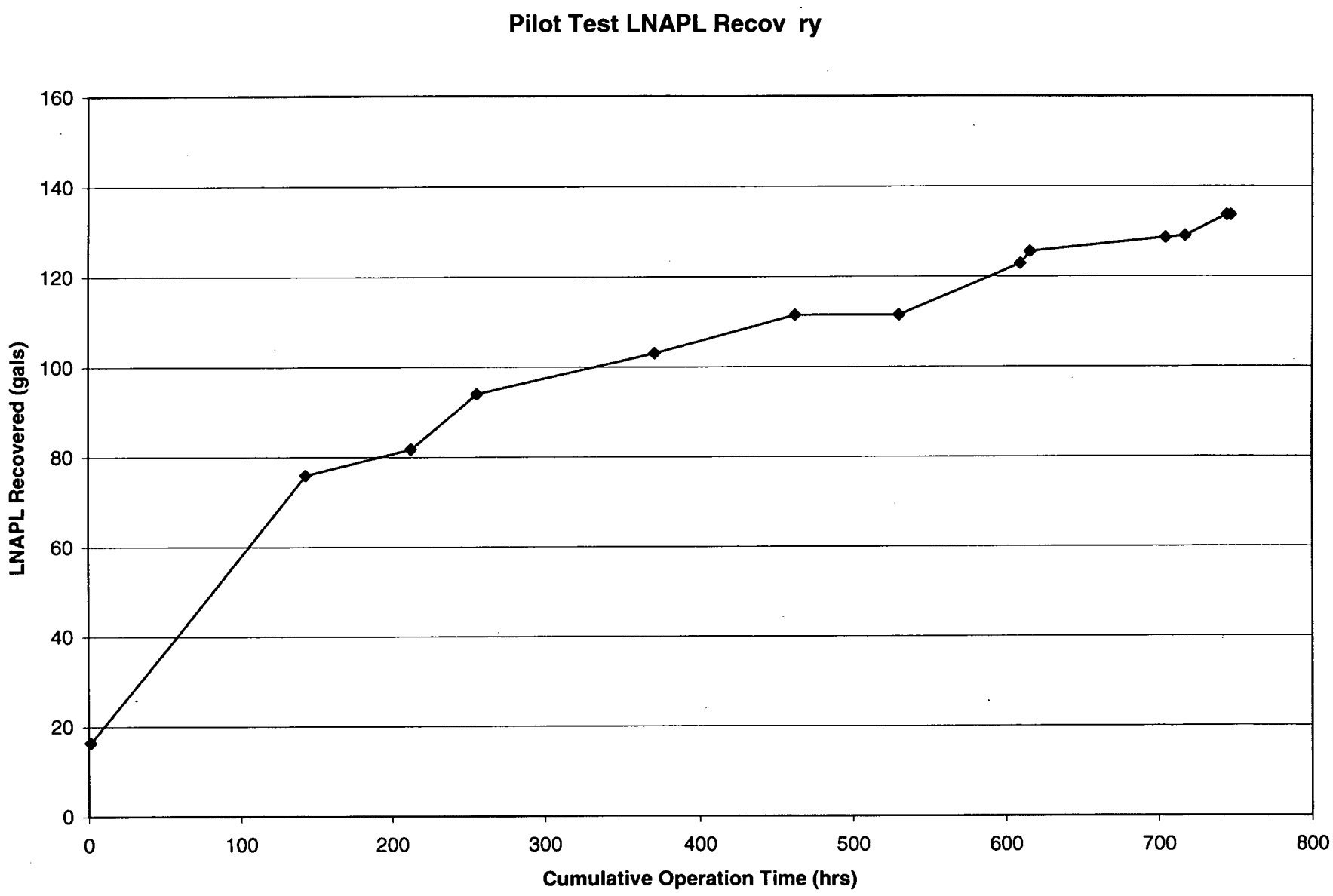

Figure 8. Pilot Test LNAPL Recovery

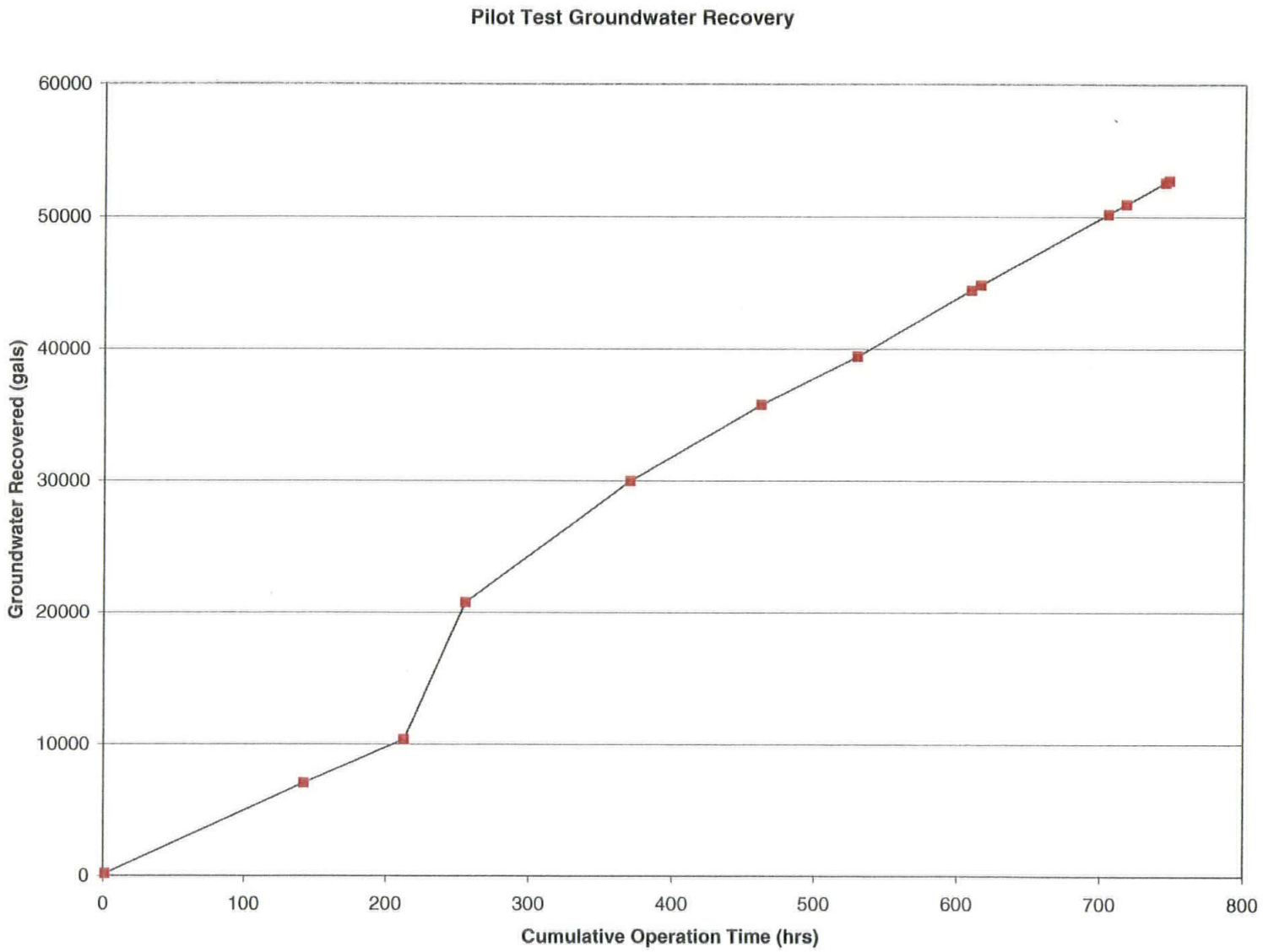

Figure 9. Pilot Test Groundwater Recovery

3.3 Extraction Wells

3.3.1 Design. Design and construction details of the bioslurper extraction wells have a significant impact on LNAPL recovery and the ratios of fluid recovery observed during operations. The bioslurper system generates a vacuum that is transferred through the well and produces a pressure gradient at the air/LNAPL interface and in unsaturated soils in the region around the well. The pressure gradient is generated in the formation throughout the entire length of the screened well section above the water table. Most of the pressure gradient energy is consumed by vapor convection in the vadose zone, but the residual gradient forces liquid (LNAPL and groundwater) into the well. The optimum well design minimizes the amount of energy lost extracting vapor and groundwater and maximizes the amount of LNAPL forced toward the well.

Extraction wells should possess a minimal length of screen both above and below the water table. However, the screened section should be long enough to intersect the mobile LNAPL layer in the formation, which may fluctuate with water table fluctuations. This design not only maximizes the available vacuum imposed on the free product layer, but also reduces the amount of water extracted by limiting the recharge area of the well. These features should result in a greater radius of influence (with respect to free product recovery), as well as more beneficial product/water extraction rates.

The wells installed at the site have 15 ft of screen placed 5 to 20 ft bgs. To determine if this is the optimum screened interval, monthly groundwater level data for the extraction wells were plotted over time. Ideally, it is desirable to use data from wells that do not contain free product; however, the majority of wells located at Site 16F contain product. The product thickness was corrected for using the following equation, where SG is the specific gravity of the product:

$$\text{Depth to Water (corrected)} = \text{Measured Depth} - \text{Product Thickness} \cdot \text{SG}$$

The specific gravity assumed for the product is 0.84 (specific gravity of diesel fuel) (Foster Wheeler, 1999a). The resulting plot is included as Figure 10. From this plot it is seen that the water table fluctuates from 3.75 to 11.75 feet from top of casing over a 2.25-year period. These measurements were taken from top of the well casings that are approximately 1 ft bgs (surveyed ground surface elevation data were not available at the time this document was prepared). Assuming the top of well casing is approximately 1 ft bgs, a screened interval of 8 ft placed between 4.75 and 12.75 ft bgs should be used at Site 16F.

3.3.2 Spacing and Locations. To capture LNAPL moving passively downgradient from the source, extraction wells were installed at what was believed to be the downgradient edge of the LNAPL plume (Foster Wheeler, 1999a). However, based on the data summarized in Foster Wheeler's bioslurper status reports, Battelle has determined that free product recovery currently is not being optimized at these wells for two reasons: (1) the wells are not spaced closely enough to each other, and (2) the wells do not exert a radius of influence over the entire free product plume.

The August to November 1999 status report states that "the oil thickness in the extraction wells rebounds when the systems are turned off for any extended duration" (Foster Wheeler, 1999b). When a bioslurper system is operated using extraction wells that are not spaced closely enough together, free product must passively migrate into the radius of influence of the wells. Thus, the bioslurper will extract the readily available groundwater but will recover little free product. However, if wells are spaced properly and if the entire plume is within the radius of influence of the extraction wells, then product outside of the radius of influence of one extraction well is within the radius of influence of another, and free product recovery will be more optimal. When the bioslurper is shut down, only product that is trapped within the water table will eventually migrate into the wells, and it will take a long time for

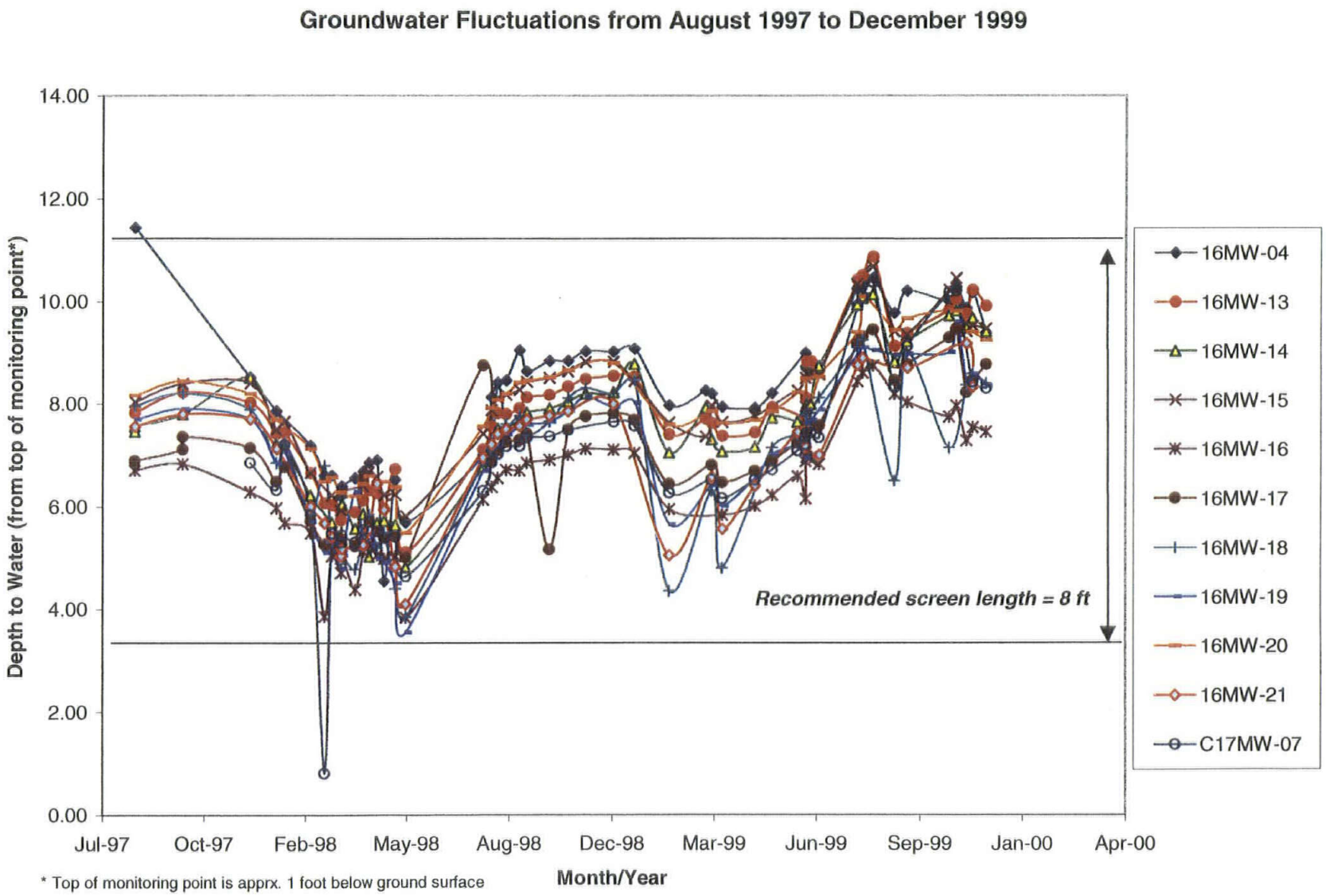

Figure 10. Groundwater Fluctuations for August 1997

this product to migrate back into the extraction wells.

Also, the August to November 1999 status report states that "the operation of the bioslurper systems in an intermittent mode appears to yield comparable monthly product quantities, while minimizing the amount of groundwater extracted" (Foster Wheeler, 1999b). Turning a bioslurper system off for a period allows time for product to migrate into the radius of influence of the wells; hence, intermittent operation does reduce the volume of groundwater that needs to be treated. However, to optimize free product recovery, wells should be installed more closely to each other, and the system should be operated more frequently (i.e., not intermittently).

3.4 Soil-Gas Monitoring Points

Soil-gas monitoring points are used for measuring the vacuum created in the vadose zone by the bioslurper and for monitoring changes in the concentrations of oxygen and contaminants in the soil gas. Monitoring points also may be used for respiration testing, where the bioslurper is shut down and concentrations of oxygen and carbon dioxide are measured. These data then are used to calculate oxygen utilization and biodegradation rates.

3.4.1 Design. Soil-gas monitoring points typically include screens at three or more depths, with the lowest screen placed 2 to 3 ft above the water table. The other screens should be evenly spaced, with a minimum of 2 ft of bentonite seal between the sandpacks associated with each screen. Figure 11 shows the construction of a typical soil-gas monitoring point.

3.4.2 Spacing and Locations. The number and spacing of the monitoring points to be installed will be determined by the results of the plume delineation. Monitoring points should be located within a set of wells or within the most contaminated areas. Additionally, two background monitoring points should be located outside of the contaminated area and beyond the influence of the extraction wells. It appears from the bioslurper status reports that the only soil-gas monitoring points at Site 16F are the three installed for the pilot test.

3.5 Process Equipment

3.5.1 Liquid Ring Pump and Heat Exchanger. The LRPs at Site 16F are equipped with small heat exchanger units on the seal water supply line between the ALS/seal water tank and the LRP. The seal water temperature becomes elevated as the seal water is recycled through the pump head. The purpose of the heat exchangers is to control the temperature of the seal water for optimum operation of the LRP. The temperature should be maintained below 100°F for optimum performance (Khidhayir, 2000).

At Site 16F it has been found that the small-diameter tubes within the heat exchanger become clogged with metal precipitates (scaling), thereby reducing the water flowrate through the heat exchanger. This effect is detrimental to site remediation for the following reasons:

- The reduced seal water flowrate adversely affects the pump's ability to create a vacuum. Hence, the LNAPL recovery rate will be less than optimum.
- Associated downtime increases the time and cost to complete site remediation.
- Equipment must be repaired and/or replaced. In February 1999, it was found that the heat exchanger on Bioslurper Unit #1 was clogged beyond repair, and the heat exchanger had to be replaced (Foster Wheeler, 1999a).

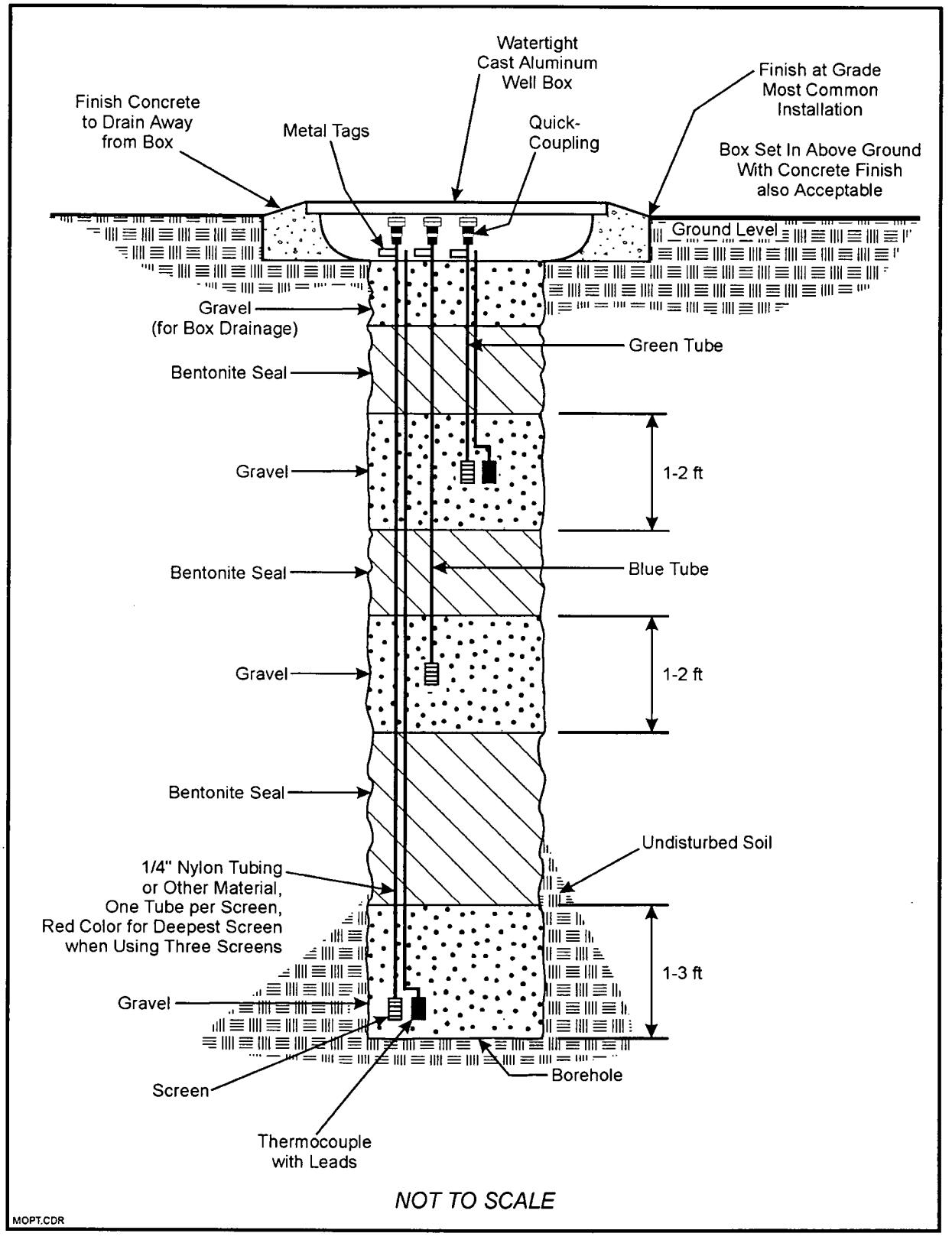

Figure 11. Typical Soil-Gas Monitoring Point

Despite the above disadvantages, the heat exchanger is beneficial to system operation overall. The maintanence schedule should include more frequent descaling with muriatic acid or equivalent as needed.

3.5.2 Oil/Water Separator. Each of the bioslurper systems is equipped with a low-profile OWS. The LNAPL and groundwater are pumped into the OWS by a progressive-cavity pump. The influent water to the OWS contains a mixture of LNAPL, water, air, and solid particles (henceforth referred to as floating solids) that floats at the LNAPL/water interface in the OWS. The presence of floating solids impedes the operation of the OWS by blocking the inlet to the fuel skimmer tube. In an effort to prevent the tube from becoming clogged with the floating solids, the OWS is operated with the inlet of the skimmer tube set at an elevated position (Figure 12), which causes oil to accumulate inside the OWS. The thicker oil layer forces the floating solids layer down into the coalescing media and away from the skimmer tube, thereby allowing the oil to flow more freely into the skimmer tube. This method of operation eliminates clogging problems associated with the skimmer tube; however, it reduces the separation efficiency of the OWS as follows:

- The available surface area of the packing is reduced. Hence, it becomes more difficult to separate the oil from the water.
- The presence of floating solids in the packing increases the likelihood that clumps of this material (containing oil) will discharge from the separator with the aqueous stream.
- Eventually, the solids reach a thickness (creating enough back pressure) in the packing so that the oil will flow through the OWS with the aqueous stream rather than separate and float to the surface.

Battelle has observed this layer of floating solids at many bioslurper sites. The skimmer-tube-design OWS can be difficult to operate in applications such as bioslurping where this floating solids phase occurs. In response to this problem, Battelle has evaluated other types of OWS. One design replaces the skimmer tube with a weir (Figure 13); Battelle has tested this design and found it to operate more effectively when floating solids are present. The LNAPL and floating solids flow over the weir into an LNAPL collection chamber, while water flows under this chamber and over a second weir to the aqueous discharge section of the OWS. For easier cleaning, the system is designed so that a valve can be closed at the aqueous outlet of the separator. This design causes the water level in the OWS to rise and forces the LNAPL and floating solids over the weir into the LNAPL collection chamber, which reduces the accumulation of floating solids and oil in the separator.

3.5.3 Hydrophobic Clay/GAC Treatment. The water treatment system consists of three 300-lb vessels of hydrophobic clay followed by two 300-lb vessels of GAC, which are all placed in series. The two most important design variables for selecting and sizing a water treatment system include water flowrate and concentrations of contaminants of concern (TPH at Site 16F). Available analytical data and flowrates obtained from bioslurper status reports (Foster Wheeler, 1999a and 1999b) for each bioslurper unit are summarized in Table 1.

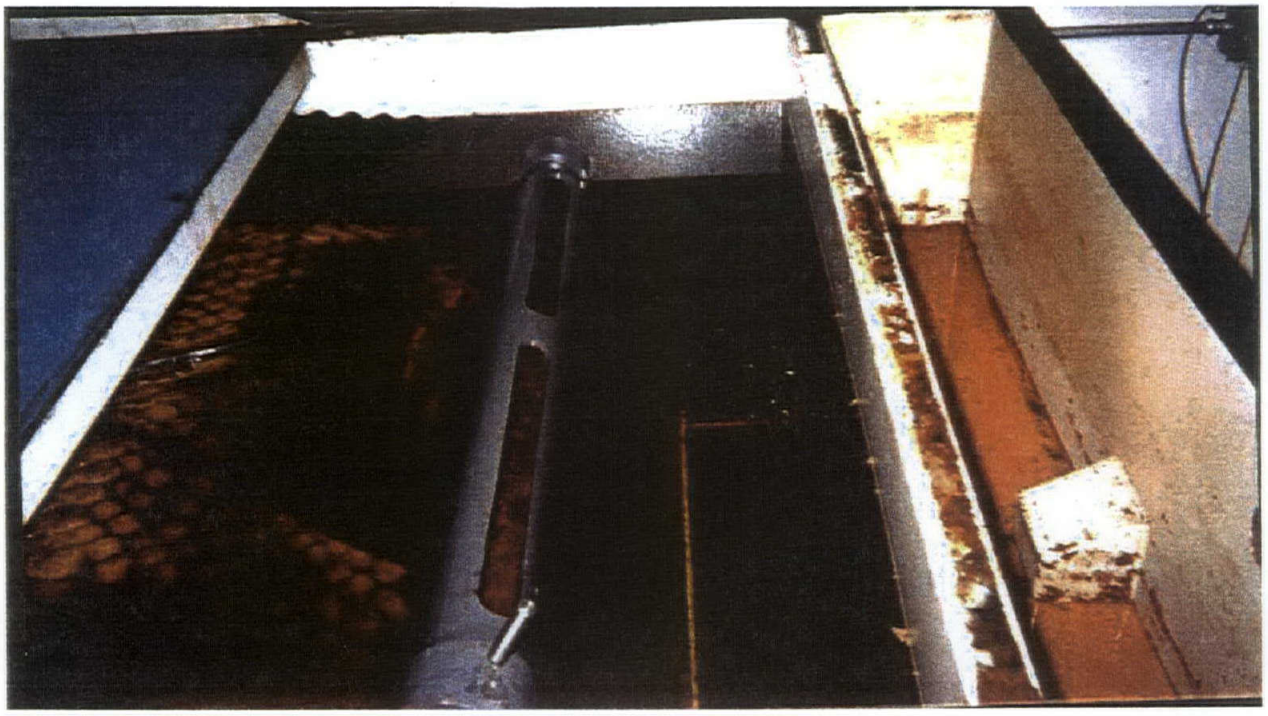

Figure 12. Oil/Water Separator

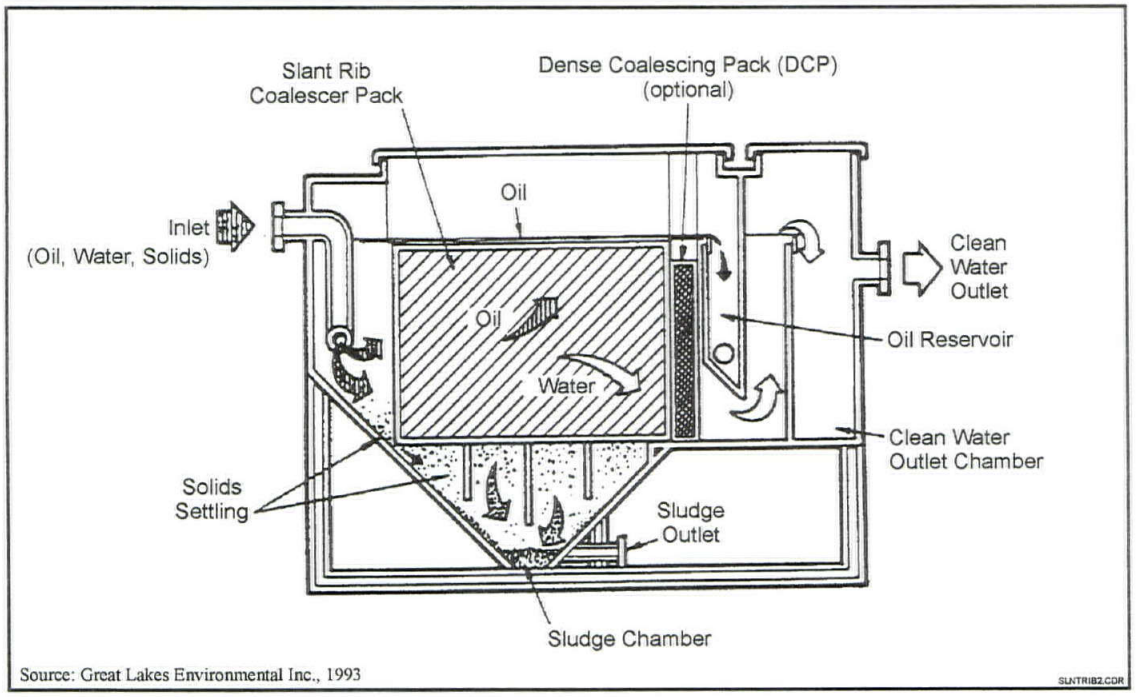

Figure 13. Diagram of Alternative Oil/Water Separator Design

Table 1. Average TPH Concentration in Effluent

Date	Untreated Effluent (ppm)	Treated Effluent (ppm)					Flowrate (gpm)
		Clay 1	Clay 2	Clay 3	Carbon 1	Carbon 2	
Bioslurper Unit #1							
Feb-98	295	12.1	ND	ND	NS	ND	12.1
Mar-98	573	101.8	113.7	14.8	5.9	2.0	7.7
Apr-98	789.5	811.5	492.5	123.7	4.7	2.0	5.0
May-98	838	639.3	1367	465	ND	ND	5.4
Aug-98	261.5	176.2	2.5	1.0	1.0	1.2	5.3
Sep-98	NS	150	134	ND	ND	ND	4.3
Oct-98	902	486	257	3	ND	ND	6.5
Nov-98	12,600	14,700	172	11.4	ND	ND	5.8
Dec-98	568.5	199.5	84.0	1.3	ND	ND	5.8
Jan-99	237	1,212.7	910.9	397.6	14.7	ND	6.3
Feb-99	1,030	258	39	2.78	1.57	ND	7.8
Mar-99	1,379	264	408	302	63.7	ND	8.1
Bioslurper Unit #2							
Feb-98	96.5	NS	NS	NS	NS	ND	5.9
Mar-98	69.1	94.8	24.9	ND	3.84	ND	8.9
Apr-98	135.6	30.8	2.7	ND	ND	ND	5.3
May-98	209.5	111.6	68	1.22	ND	ND	5.5
Aug-98	91.95	1.0	ND	ND	ND	ND	5.8
Sep-98	116	16.8	8.8	NS	ND	ND	3.3
Oct-98	19.2	ND	ND	NS	ND	3.3	23.2
Nov-98	31.5	2.1	ND	NS	ND	ND	12.3
Dec-98	150.5	1.0	ND	NS	ND	ND	4.7
Jan-99	52	1.2	ND	NS	2.86	ND	7.0
Feb-99	47.9	92.8	ND	NS	ND	ND	0.6
Mar-99	271	122	ND	NS	ND	ND	7.7

ND = not detected.
NS = not sampled.
ppm = parts per million.

Several observations can be made from these data. First, concentrations of TPH in the aqueous effluent from Unit #2 are much lower than those from Unit #1. This result is expected because product recovery of Unit #2 is much lower than Unit #1. Another observation that can be made is that the hydrocarbon concentration in the influent to the water treatment system is extremely variable. For example, the influent sample collected January 26 contained only 80 ppm TPH; however, one month later, 1,080 ppm was detected in the sample, representing a 1,350 percent increase. One reported result was as high as 12,600 ppm. A third observation is that the clay media has not been changed out frequently enough to treat process water effectively. A high concentration of TPH was reported in the effluent from the third vessel of hydrophobic clay during the months of January and March 1999 (Table 1). In January 1999, the influent TPH concentration at the first clay vessel at Unit #1 was less than its effluent concentration. This phenomenon, known as desorption, occurs when the clay and/or GAC becomes saturated with hydrocarbons, thereby causing the effluent stream to contain a greater concentration of contaminants than the influent stream. Not changing the clay frequently allows high concentrations of hydrocarbons to enter the GAC, and thereby will increase the operating costs for the project.

Figure 14 shows the monthly cost of operation for Bioslurper Unit #1 using TPH concentration and flowrate data collected in March 1999 (Foster Wheeler, 1999a). The average TPH concentration in the influent streams to the clay and to the GAC was 1,379 and 302 ppm, respectively. It assumes that the bioslurper system was operated continuously at an average flowrate of 8.1 gpm. The cost to operate the system at the same influent concentration but changing the clay more freqently (and lowering the effluent TPH concentration to 30 ppm) is presented for comparison. The data indicates that operating cost for the clay/GAC treatment system can be reduced by one half by maintaining the concentration of TPH in the influent stream to the GAC less than 50 ppm. The monthly cost of operation also was calculated at lower influent TPH concentration to the clay vessel in order to show the range of monthly costs of operation for Unit #1 based on reported analytical data.

Battelle was not able to obtain Foster Wheeler's line-item costs in order to calculate a monthly cost figure. Instead, the monthly cost figure was generated using the following assumptions (values used in these assumptions were gathered from vendors and may not exactly reflect the values for the media used at NWS Earle):

- The clay is capable of absorbing up to 50-60% by weight of hydrocarbons (Napolitano, 2000). Note that this figure represents ideal conditions. In actual applications, a significant amount of channeling can occur which reduces the efficiency of the clay. In addition, because the clay swells as it absorbs hydrocarbons, the clay becomes plugged and in some instances may be disposed of before it is used to its full capacity.

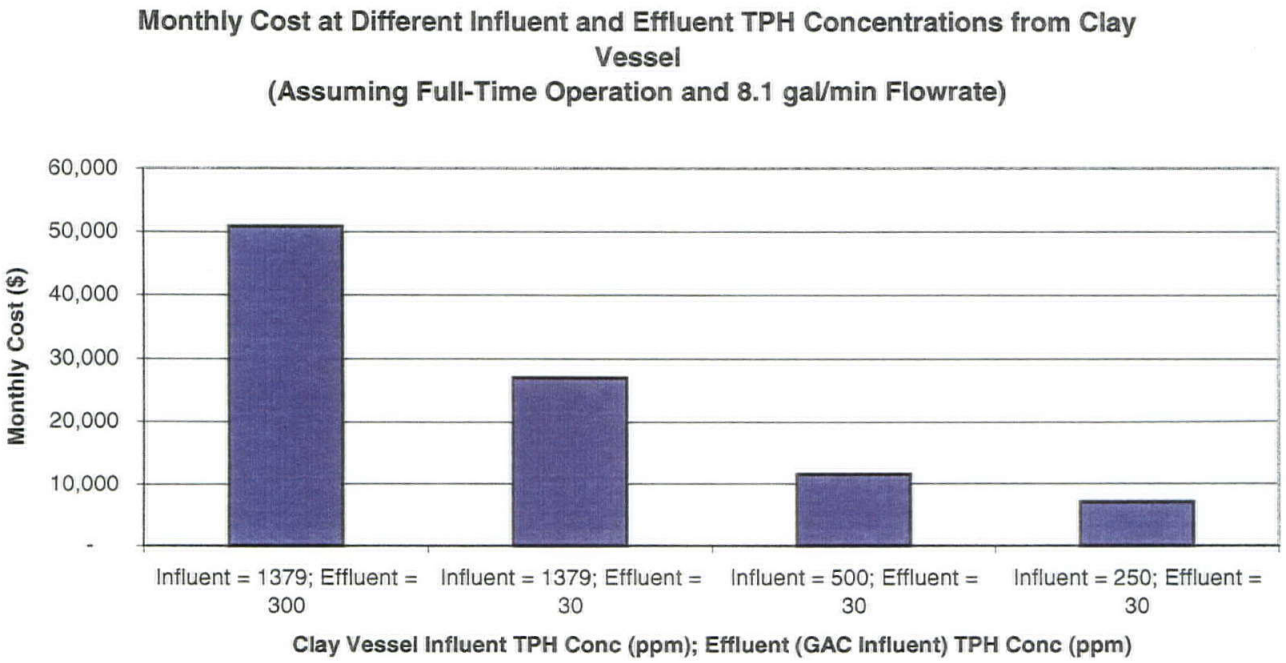

Figure 14. Monthly Cost at Different Influent and Effluent TPH Concentrations from Clay Vessel

- Under ideal conditions, the GAC can absorb up to 7.5 percent by weight in hydrocarbons (Napolitano, 2000). The actual hydrocarbon composition of the TPH will affect adsorption rates and determine when breakthrough will occur. For example, GAC has a greater ability to adsorb xylenes than benzene. The time to breakthrough also is affected by the formation of channels.

- The labor cost to replace clay is 1.4 times that to replace the carbon, which was calculated based on a quote for supplying and replacing 2,000 lb of clay or carbon (Great Lakes Carbon, 1999).

- The cost for virgin activated carbon is $0.85/lb, and that of clay is $1.20/lb (Great Lakes Carbon, 1999)

- The disposal cost for both clay and activated carbon is $0.45/lb (Great Lakes Carbon, 1999). Both materials are assumed nonhazardous.

- Costs to deliver virgin carbon and clay and pick up the spent material are not included in this estimate.

The operating costs for the water treatment system shown in Figure 14 range from a low of $7,000 to a high of $51,000. The wide range of operating costs makes it difficult to ascertain the performance of the treatment system in relation to the operating cost. However, operations reports (Foster Wheeler, 1999a and 1999b) do not specify data such as how long the system was operating prior to sample collection, which wells were being extracted from, system flowrates, groundwater elevations (at wells not being extracted from), and drop tube elevations at the time of sample collection. Without these additional data, it is not possible to determine why the TPH concentrations in the influent streams fluctuate so widely.

Typically, for bioslurper processes, concentrations are very high at the onset of remediation, but they decrease rapidly during the first few months (Figure 15). The variable concentrations at Site 16F may be a result of operating the bioslurper system in an intermittent fashion and/or not allowing the system enough time to reach steady state before collecting the aqueous samples; alternately, variable concentrations may be the result of modifying the operation of the system (i.e., operating with different extraction wells, or raising or lowering the drop tube). The performance (and operating cost) of the treatment system is greatly affected by variations in influent stream TPH concentrations, so it is important to understand why TPH concentrations vary so widely.

The water treatment system, specifically the frequent consumption of the clay/anthracite media, is the chief reason for the low operational time of the bioslurper units. Clay/anthracite media typically absorbs up to 60 percent by weight in hydrocarbons. The high solids and oil and grease content in the aqueous OWS effluent pumped into the clay units requires that the clay media be replaced approximately every 50 hours of operation, which results in a high operational cost (Heffron, 2000). Therefore, to reduce monthly operational costs, Foster Wheeler operates the system approximately 8 hours a week. Although monthly operational costs are reduced, this schedule results in increased time to remediate the site. Costs, such as management, sampling, and monitoring, will be incurred whether or not the system is operating at full capacity. Strategies for optimizing the operation of the bioslurper system to reduce costs and to reduce the time necessary to complete free product removal activities are discussed in Sections 4.0 and 5.0.

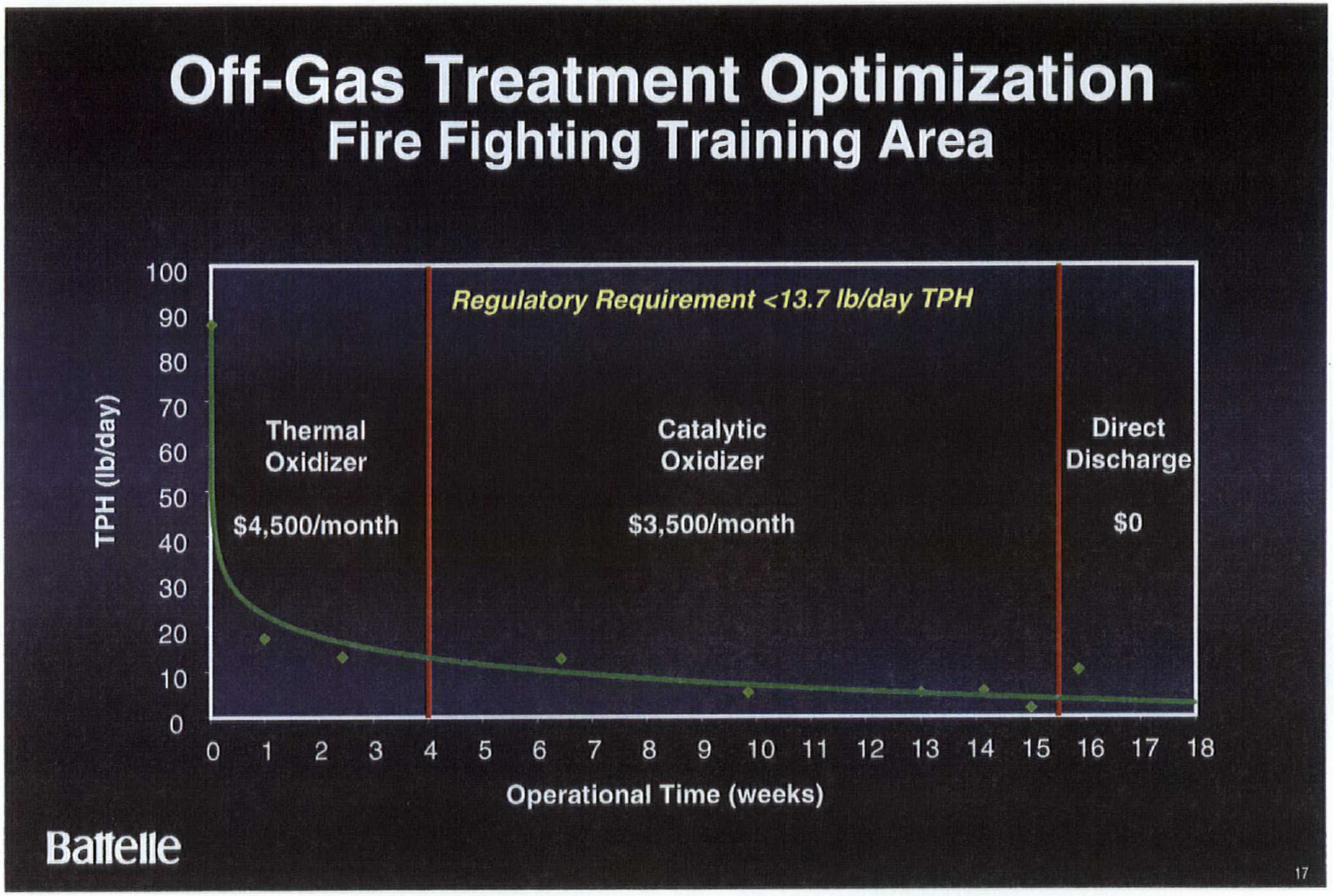

Figure 15. Panama City TPH Conclusion

3.5.4 Vapor Treatment. A vapor treatment system consisting of two 300-lb vessels of gas-phase GAC was installed to treat the off-gas generated by Unit #1. The impetus for installing the vapor treatment unit was a slight violation of the NJDEP Air Discharge Permit Levels. A sample collected from the vapor effluent from Unit #1 on April 3, 1998, indicated a total volatile organics concentration of 27.3 ppm by volume, which is 0.3 ppm above the 27 ppm limit. At the vapor discharge rate calculated from the differential pressure in the exhaust stack, the volatile organic discharge rate was 0.039 lb/hr, just above the limit of 0.035 lb/hr. Although none of the earlier samples exceeded the limits, the GAC vapor treatment system was installed to treat the off-gas generated by Unit #1 to ensure that no additional violations would occur. A vapor treatment system was not deemed necessary for Unit #2 because hydrocarbon concentrations in the bioslurper effluent from this unit are much lower than those observed from Unit #1.

Foster Wheeler submitted two revised Air Discharge Permit Applications to the NJDEP for the bioslurper systems. One of the revised permits reflected the installation of the treatment system at Unit #1, and the other elevated the discharge limits from both units to the maximum allowed by NJDEP. Copies of the revised air discharge permits were not available at the time of this writing. The construction of the vapor treatment system and the modification of the air discharge permits occurred in July 1998 (Foster Wheeler, 1998b).

It is important to note that the adsorption capacity of gas-phase GAC is significantly affected by both temperature and relative humidity. Some carbon vendors recommend that the influent vapor stream be kept below 140°F and 50 percent relative humidity (Napolitano, 2000). The adsorption capacity of the carbon is maximized within these range of values. Vapor temperature and relative humidity data were not included in the bioslurper status reports. These parameters should be monitored to ensure that they are within the GAC manufacturer's specification.

3.5.5 System Controls and Alarms. The controls and alarms associated with the bioslurper systems are described in Section 2.5. In the event of an unscheduled system shutdown, the master control panel sends a message via fax or pager to Foster Wheeler, the NWS Earle ROICC, the NWS Earle Fire Department, and Naval Facilities Engineering Command Northern Division. The fire department responds to all shutdown alarms by dispatching a unit to the site. In the past, these alarms have been activated several times outside of normal buisness hours, and the Fire Department has dispatched a crew to the site only to find the system shut down. Disturbance caused by after-hour shutdowns of the bioslurper systems makes operation outside of regular business hours difficult. The Fire Department must expend valuable resources to respond to a non-hazardous situation. As a result, Foster Wheeler has been asked to operate the system during regular business hours, or approximately 7:00 a.m. to 5:00 p.m., weekdays. Hence, the maximum number of hours that the bioslurper could operate in a week is approximately 50 hours, which is not cost-effective. The length of time to remediate the site increases significantly resulting in greater O&M costs (Section 5.0).

Eight of the nine high and low switches installed in the various system components do not constitute an emergency or indicate a leak. The notification system currently in use distinguishes between the various shutdown alarms (Heffron, 2000). The fire department should not respond to the activation of any alarm that does not constitute an emergency. The switches have been installed to prevent a spill from occuring; the switches shut down the bioslurper system (and call the Fire Department) if a high (or low) level situation occurs.

As long as the activation of these switches shuts down the LRP and transfer pumps, then the control system is working as designed, and a spill will not occur. However, if a switch fails, a spill could occur, and under this scenario the alarm system **would not** be activated. Therefore, a ninth "failsafe" switch was installed in each bioslurper unit. These switches are located in a sump in the floor of each

unit. If a leak or spill occurs, the sump will fill and the switch will shut down the bioslurper and notify the Fire Department. Activation of this alarm should trigger a rapid response from Base personnel to ensure that an accidental release does not occur.

The programming for the alarm system must be modified to notify the Fire Department only if the sump alarm is activated. The programming can be easily modified with the ProView™ software that is used to control the operation of the system.. Procedures may be found in the manufacturers literature which is included as an appendix to the operations and maintenance manual for the site (Foster Wheeler, 2000).

The bioslurper systems also are equipped with an automatic restart capability. In the event of a shutdown, Foster Wheeler can restart the system from a remote location. However, for the following reasons, this automatic restart function offers only limited benefits. First, in the event of an unattended shutdown, an operator should go out to the site to inspect the system prior to restarting it. If an inspection is not performed to determine the cause of the shutdown and the problem is not corrected, then either the system will not restart, it will shut off again, or a spill or other potentially hazardous situation could develop. Second, the restart system could be used to restart the system after an intentional shutdown; however, typically an intentional shutdown would be initiated only during testing or routine maintenance. For these situations, an operator would be present on site. In addition, Section 6.0 of the operations and maintenance manual for the bioslurper systems (Foster Wheeler, 2000) lists a number of steps required before starting the systems, including the manual adjustment of valves and the OWS skimmer pipe; these operations cannot be performed remotely. Overall, the design and installation of this type of equipment increases capital costs and it makes the system more complicated by increasing the chance for equipment malfunction and downtime.

3.6 System Operation

Operation of the full-scale bioslurper systems began in February 1998. Bioslurper Unit #1 is designed to extract liquids from wells 16MW-13, 16MW-14, 16MW-15, and 16MW-04. Unit #1 also extracts soil vapor from the two bioventing wells, 16MW-22 and 16MW-23. Bioslurper Unit #2 is designed to extract from wells 16MW-16, 16MW-17, 16MW-19, 16MW-20, and C17/20MW-07. Battelle has evaluated system performance data and operating procedures. Results are presented in this section.

3.6.1 Fluid Recovery. The volume of LNAPL and groundwater recovered by each bioslurper units has been documented (Foster Wheeler, 1999a and 1999b). From February 1998 through November 1999, Unit #1 recovered approximately 3,000 gallons of LNAPL, and Unit #2 recovered approximately 400 gallons. Over the same time period, Units #1 and #2 recovered approximately 315,500 and 168,000 gallons of groundwater, respectively (Foster Wheeler, 1999b). For every gallon of LNAPL recovered, Unit #1 recovered approximately 105 gallons of groundwater, and Unit #2 recovered approximately 420 gallons of groundwater.

The mass of hydrocarbons recovered in the groundwater and soil vapor also has been calculated using contaminant concentrations and flowrates. From February 1998 through November 1999, Unit #1 recovered approximately 2,020 lb of TPH dissolved in the groundwater, and Unit #2 recovered approximately 140 lb. Over this same period, Units #1 and #2 recovered approximately 482 and 136 lbs of TPH, respectively, from the vapor phase (Foster Wheeler, 1999b). The weight of hydrocarbons removed in the aqueous and vapor phases can be converted to volume using the specific gravity of diesel fuel: Assuming a specific gravity of 0.84, Unit #1 has recovered 291 gallons of hydrocarbons in the aqueous phase and 69 gallons in the vapor phase, and Unit #2 has recovered 20 gallons in the aqueous phase and 20 gallons in the vapor phase.

Cumulative hydrocarbon recovery at Unit #1 and Unit #2 is plotted in Figures 16 and 17, respectively. It is apparent that Unit #1 has removed significantly more hydrocarbon contamination than Unit #2, probably because there is more available product in the area of the wells that Unit # 1 is extracting. The wells that Unit #1 are extracting from are located in the southern portion of the site while Unit #2 is extracting from wells located in the northern portion of the site. More product may be available in the southern portion of the site. It is important to realize that although contouring programs show the plume as being continuous, in reality the plume may be composed of several discrete pools of product. Installing additional wells and monitoring the free product thickness will improve the accuracy of the plume delineation. Recommendations for installing additional wells are provided in Section 4.2.1.

Biodegradation of TPH in the subsurface also occurs due to the movement of air through the vadose zone during bioventing and bioslurping. Calculations presented by Foster Wheeler indicate that 8,470 lb of hydrocarbons were biodegraded by Unit #1 and 3,730 lb were biodegraded by Unit #2 through April 1999 (Foster Wheeler, 1999a).

3.6.2 Drop Tube Placement. Currently, the openings of the drop tubes in the extraction wells are placed at the top of the LNAPL layer (Heffron, 2000). Typically, bioslurper drop tubes are placed at the LNAPL/water interface in the well. Experience at other sites indicates that placing the drop tube opening above the interface can cause mounding of the groundwater table. The locally mounded water table saturates the pores with water, which then can obstruct the flow of LNAPL into the well by lowering the relative permeability of the formation to LNAPL. The effect of this situation is reduced LNAPL extraction rates. A discussion of relative permeability can be found in Domenico and Schwartz (1990).

3.6.3 Downtime. The bioslurper systems currently are operating approximately 8 hrs/wk (Heffron, 2000). The exact date of the transition to 8 hrs/wk operating time could not be determined from the available reports. The bioslurpers were operated for over 80 hrs/month each as recently as November 1999, or approximately 20 hrs/wk (Foster Wheeler, 1999b). The operating time has been reduced for the following two reasons:

- To comply with a request from NWS Earle to operate the system only during typical working hours (Monday through Friday 7:00 a.m. to 5:00 p.m.).
- To reduce monthly operating costs.

NWS Earle has asked that the bioslurpers be operated during regular working hours so that Foster Wheeler is available to respond to the system in the event of an alarm condition. In the past, the Base Fire Department had been called several times to respond to problems that turned out to be nonhazardous. This problem can resolved by reprograming the controller for the bioslurper system to only call the Fire Department if a potentially hazardous situation occurs (see Section 3.5.5), and by negotiating approval with NWS Earle to operate the system continuously.

The operating cost is significantly reduced by only operating the bioslurper system for 8 hours a week, because less water is extracted. Another advantage of intermittent operation is that it allows time for LNAPL to passively migrate into the well's radius of influence. However, if the bioslurper system is designed with a sufficient number of extraction wells with closer spacing, the system will not depend on passive LNAPL migration for LNAPL recovery. Rather than only operating the system for 8 hours, the cost and performance of the water treatment system must be evaluated by treatability testing to determine if it is the proper technology for the site (see Section 4.3). Also, because the water treatment requirements at the site are extremely stringent (and hence have a significant impact on operating cost), an attempt should be made to renegotiate them with the Base Wastewater Treatment Plant.

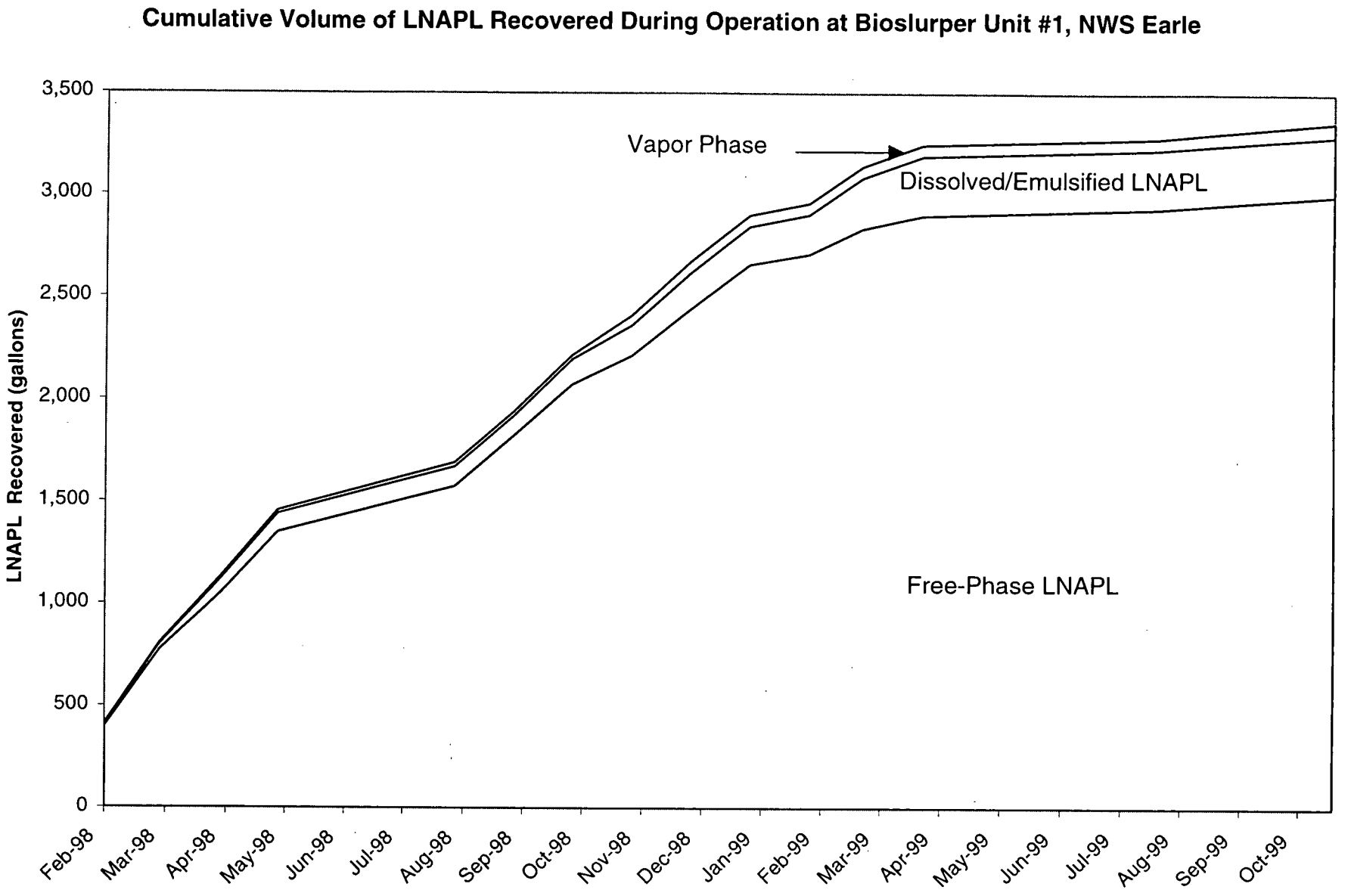

Figure 16. Unit #1 Cumulative LNAPL Recovery

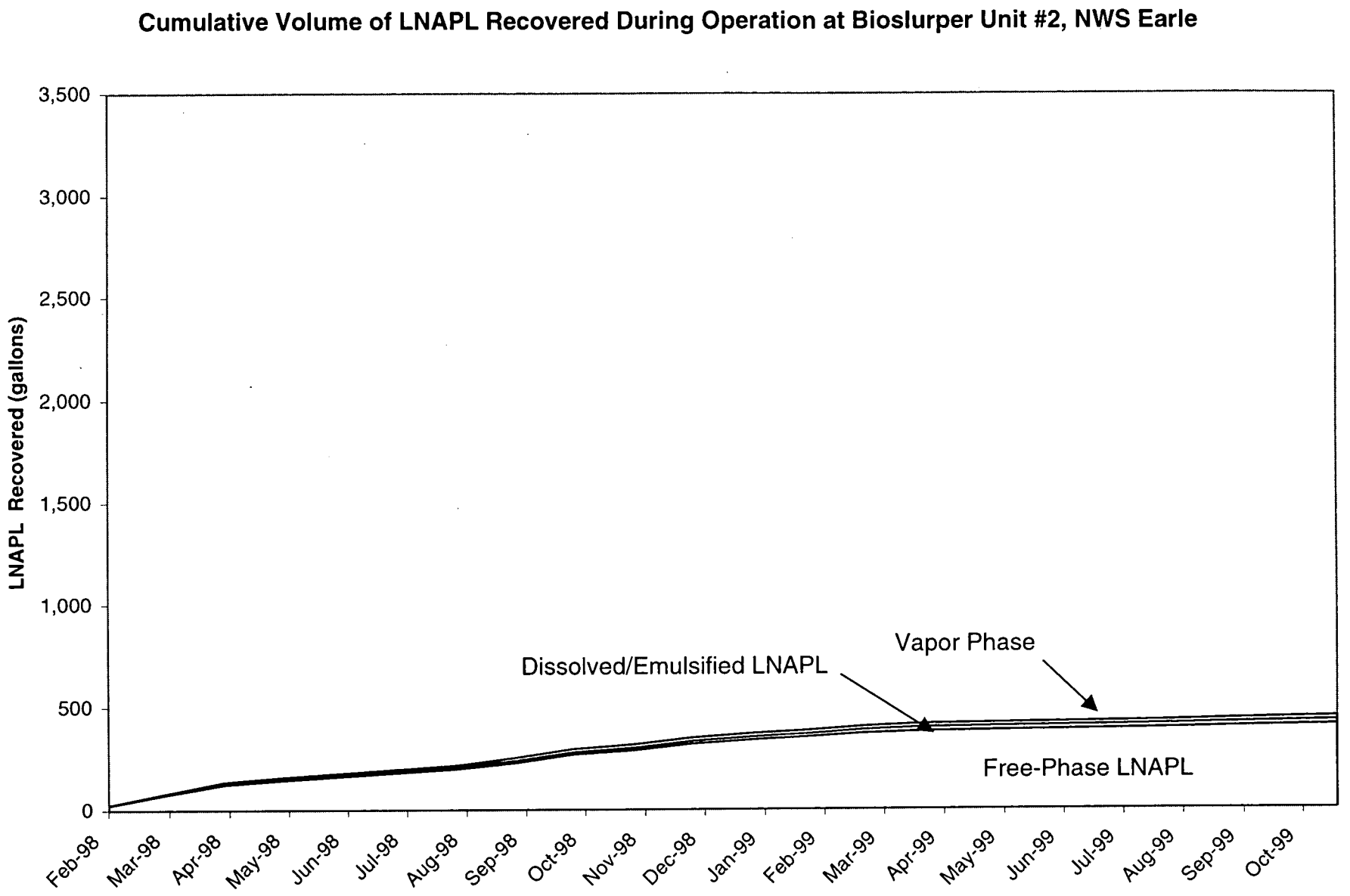

Figure 17. Unit #2 Cumulative LNAPL Recovery

3.7 Groundwater Monitoring Program

Groundwater sampling activities at Site 16F are summarized in the *Year 1 Groundwater Monitoring Report for Remedial Action Implementation, Buildings C-17/20/16/50* (Tetra Tech NUS, Inc., 1999). This report includes groundwater sampling results for 8 monitoring wells sampled on four occasions between August 1998 and May 1999 (August and November 1998, and February and May 1999). According to the Groundwater Monitoring Report, the NJDEP has approved natural attenuation as the long-term remedial action for dissolved benzene in the groundwater, and has also granted a Classification Exception Area (CEA) for the site (Tetra Tech NUS, Inc., 1999).

The objective of the groundwater monitoring program is to "assess and document migration, degradation, and attenuation of target constituents at the site" (Tetra Tech NUS, Inc., 1999). The program includes short-term monitoring and provisions for long-term monitoring if NJDEP Groundwater Quality Standards (GQSs) are exceeded during the short-term monitoring. The groundwater samples are to be analyzed for BTEX components and naphthalene. Ten wells are included in the monitoring schedule; however, due to active LNAPL recovery efforts, samples were not collected from wells 16MW-04 and 17MW-01. Samples were collected from wells 16MW-02, -03, -05, -06, -08, and –10; 17MW-02, and 18MW-01. The wells included in the monitoring program are shown on Figure 18, with embedded tables containing the analytical results from the sampling events. Trend plots of benzene concentration for these sampling events were prepared from the analytical data. Concentration curves for wells 16MW-02, -03, -08, -10, 17MW-02, and 18MW-01 are plotted on Figure 19. For the purpose of scale, the benzene concentration at 16MW-06 is included as a separate plot (Figure 20). Well 16MW-05 was omitted from these curves due to the existence of only two data points. Tetra Tech has stated that the monitoring data suggest that the dissolved hydrocarbon plume has not expanded during the quarterly sampling effort, and has also concluded that the increase in the benzene concentrations at 16MW-06 "appears unrelated to the plume of contamination within the CEA" (Tetra Tech NUS, Inc., 1999).

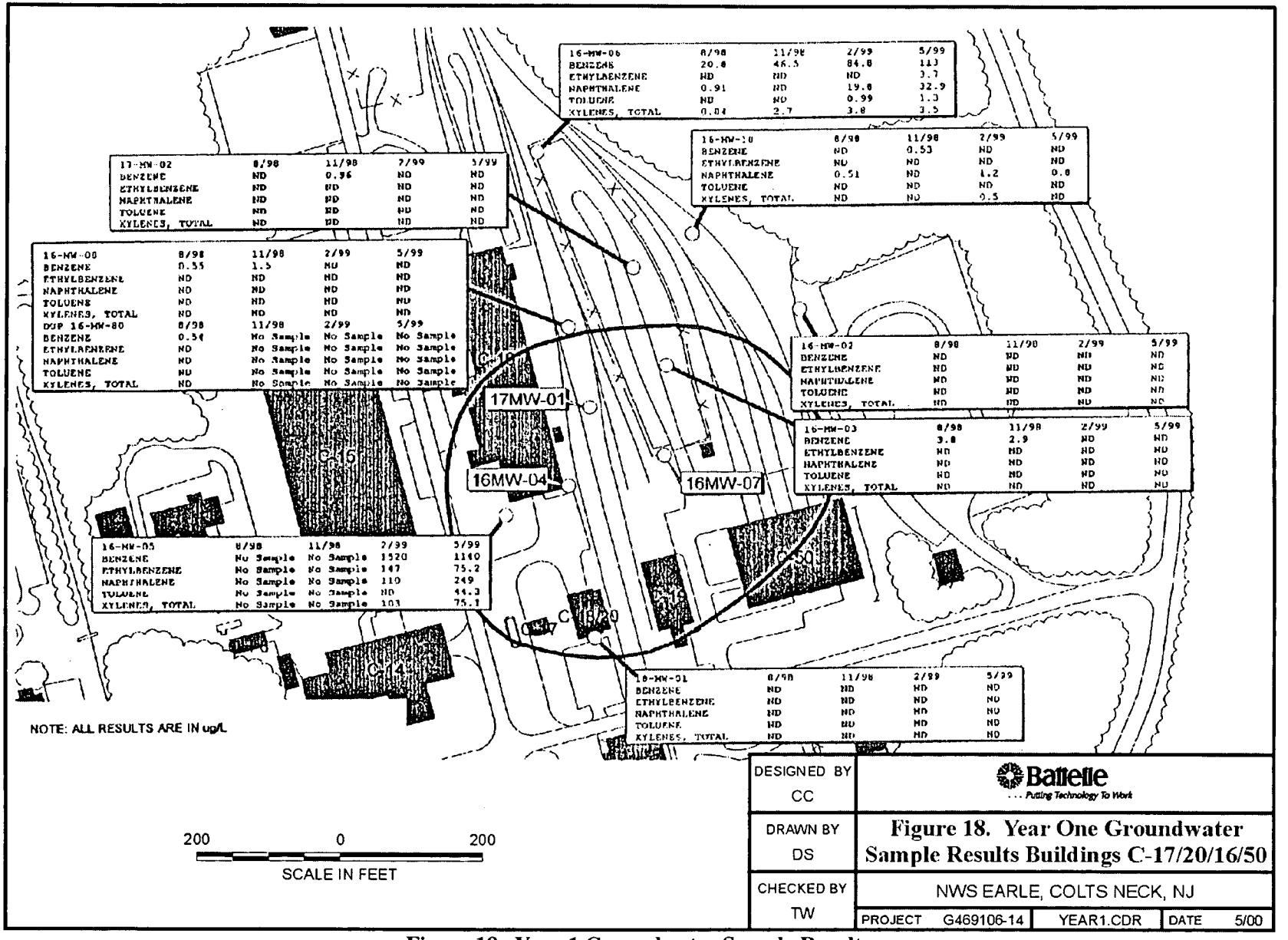

Figure 18. Year 1 Groundwater Sample Results

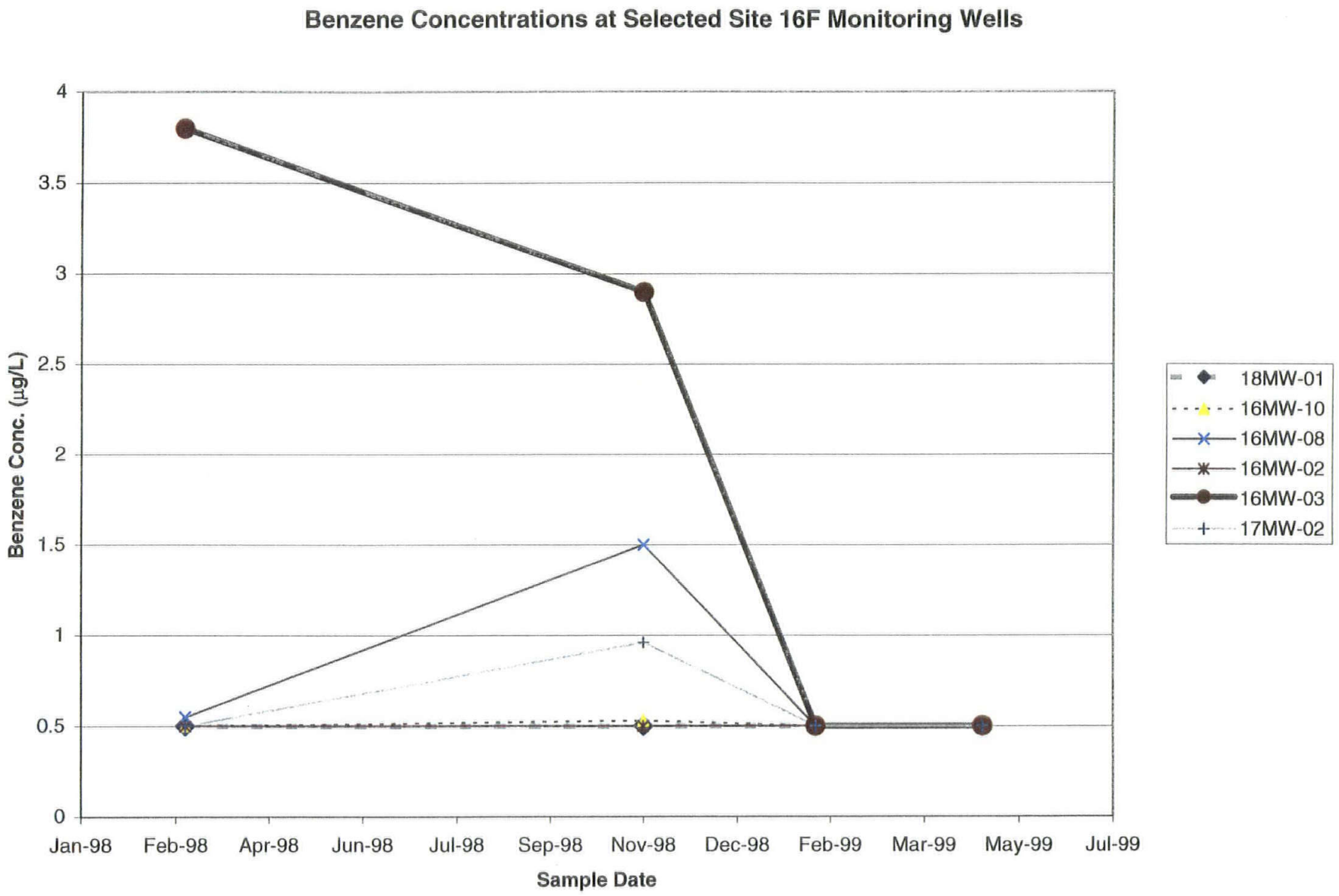

Figure 19. Benzene Concentrations at Selected Site 16F Monitoring Wells

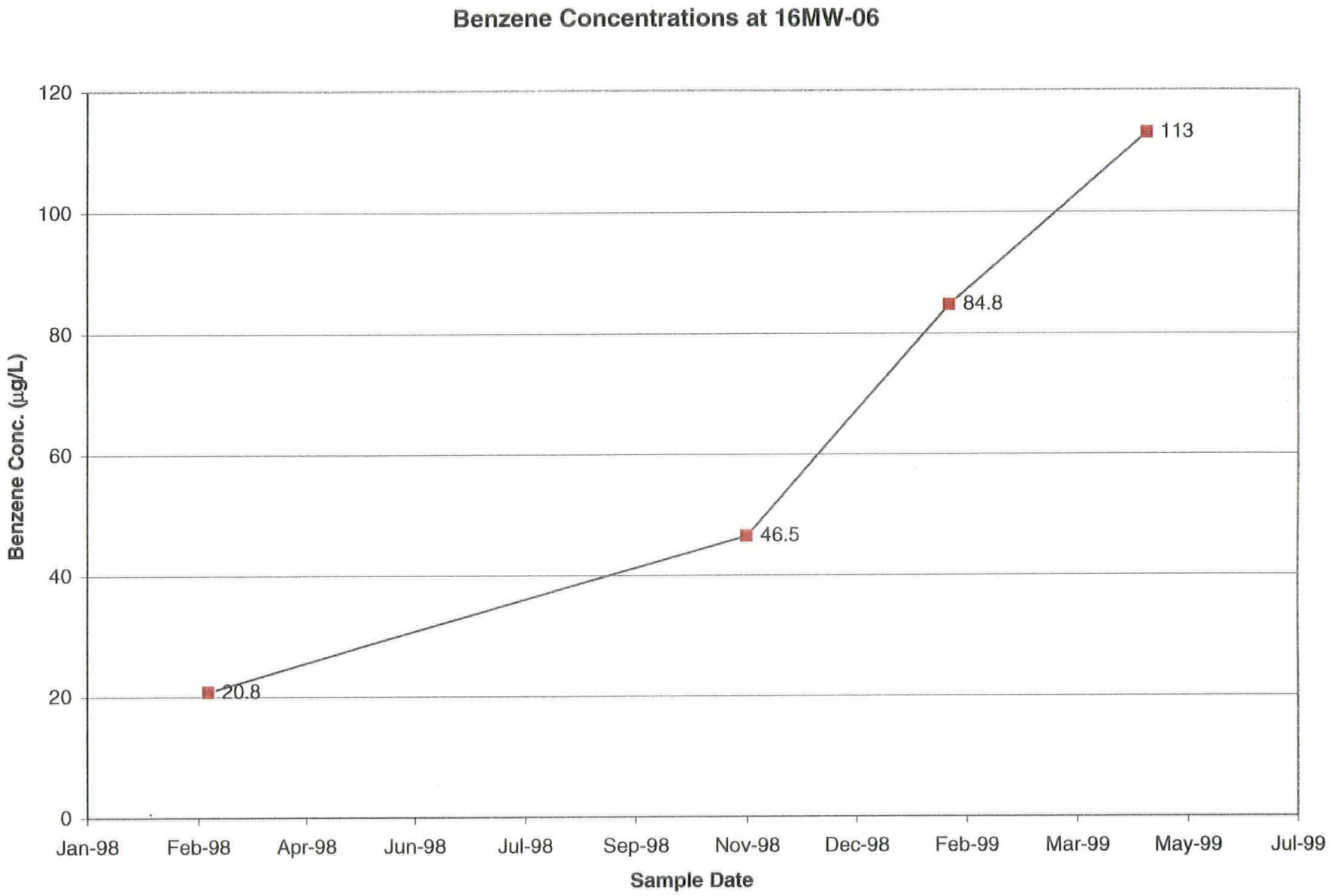

Figure 20. Benzene Concentrations at 16MW-06

Section 4.0: RECOMMENDATIONS

Bioslurping appears to be an effective technology for source removal at Site 16F. However, system optimization and additional monitoring are required to reduce the cost and minimize the overall duration of site cleanup. Frequent shutdowns, short operating time, and high operating costs are a few of the problems that are associated with the implementation of this technology at Site 16F. These problems can be resolved through optimizing the system and implementing an appropriate monitoring program. Figure 21 is a flow chart that illustrates recommendations to improve the operation and reduce O&M costs of the system. These recommendations should be used as a guideline for improving the performance of the bioslurper systems.

4.1 Cleanup Objectives and Exit Strategy

One of the first steps in remedial design and implementation is to develop an exit strategy in order to meet the cleanup objectives as rapidly as possible while keeping the cost to a minimum. It is important to remember that the exit strategy is a process that evolves continuously throughout the project; the project consultants and managers should keep the regulatory agency informed as necessary. Project optimization and frequent analysis of performance data are essential to successful development and implementation of the exit strategy. The following recommendations (consistent with the steps listed in Figure 21) are necessary to achieve the cleanup objectives of removing LNAPL to the extent practicable and closing out the site:

- Use pilot test data and published literature/data to establish that bioslurping is the best demonstrated available technology (BDAT) to recover LNAPL.

- Optimize the LNAPL recovery system (number/distribution of extraction wells) and water treatment systems. Low recovery at the end of the project should be used to justify turning the system off; at this point, the system has reached the diminishing return stage and recovery by the BDAT is complete (to the extent practicable). Use cost data (e.g., cost per gallon of LNAPL recovered is significantly high as compared to the beginning of the project).

- Monitor groundwater over the bioslurper operational period and establish the fact that dissolved concentration/mass of the contaminants of concern (COCs) from the LNAPL source is decreasing or stable.

- Consider alternative technologies (following bioslurping) to further remove the source only if the dissolved COCs are moving at a rate that can impact the environment and/or human health (even after natural attenuation effects are considered).

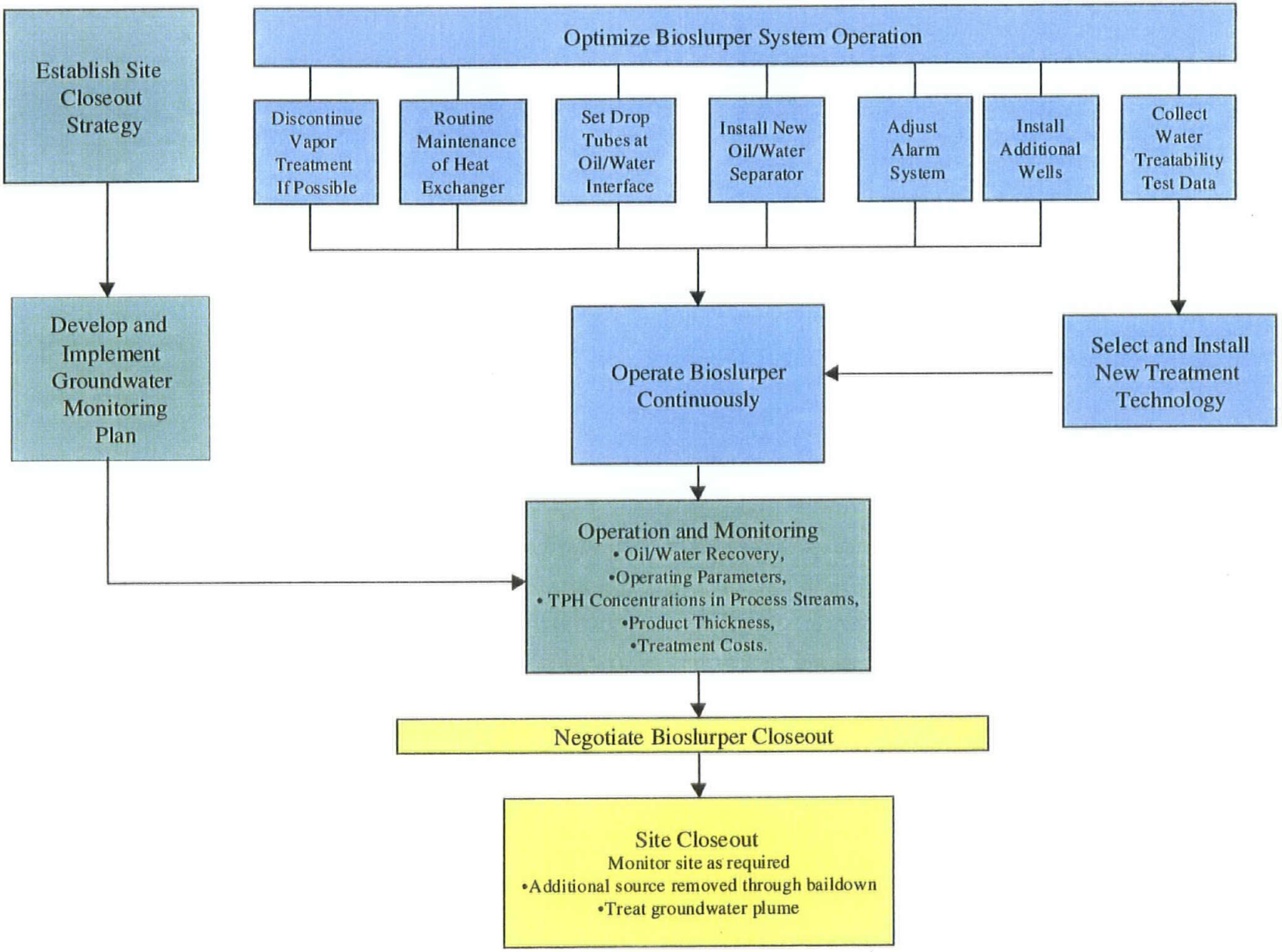

Figure 21. Decision Diagram for Bioslurper Exit Strategy and Site Closure

4.2 Bioslurper System Optimization

The operation of the bioslurper should be adjusted to achieve the remedial objectives in a more efficient manner. The system should be optimized to maximize the mass of hydrocarbons recovered while minimizing the cost of operation. Recommendations to improve the operation of the system include:

- Install additional extraction wells and soil-gas monitoring points.
- Set drop tubes at the oil/water interface.
- Install a new OWS.
- Monitor and possibly discontinue treatment of off-gas.
- Reprogram the alarm controller.
- Periodically add anti-scaling compound to heat exchangers.
- Operate the bioslurper system continuously.

Upon implementing these recommendations, the system should be operated continuously; system performance and operating costs may then be evaluated. Additional system modifications and/or operational procedures may be implemented based on the new cost and performance data.

4.2.1 Extraction Well Installation and Plume Delineation. A significant amount of free product has been recovered at Site 16F; however, the bioslurper systems likely are capable of recovering the product at a greater rate. Currently, the systems are being operated as an enhanced skimmer, and not as vacuum-enhanced free product recovery systems. The systems are being operated for only a few hours a week, which is uncharacteristic for a bioslurper system. While on, the systems remove the available product within the radius of influence of the extraction wells. The systems are then shut down for about a week. During this time, product migrates passively into the radius of influence of the extraction wells (and into the extraction wells) from the soils located outside of the influence of the wells. The time limiting factor, therefore, is the amount of time that it takes for product to migrate back into the radius of influence of the extraction wells. If the wells are spaced closer together and cover the entire product plume, then product recovery can be completed faster and hence will reduce total operating time and costs. Therefore, it is recommended that additional extraction wells be installed at Site 16F. These wells will help to define the limits of the plume and will improve the ability of the bioslurper system to remove LNAPL. The wells should be placed so that the distance between any two wells does not exceed the radii of influence of the extraction wells (Battelle, 1998). A diagram of an extraction well layout for a generic site is shown in Figure 22. The radii of influence of the extraction wells overlap and include the entire area of the LNAPL plume. The distance between the extraction wells (L) in this configuration is determined from the equation:

$$L = 2r \cos(30) = 1.73r$$

where r = the radius of influence of the extraction well.

Based on a 1.5-acre LNAPL plume (Figure 2) and assuming a radius of influence of 25 ft (Heffron, 2000), 33 additional extraction wells should be installed. This number was determined from a well spacing of approximately 43 ft, as calculated from the above equation. Of these 33 wells, 23 should be installed in the plume adjacent to C-16 and 10 should be installed in the plume adjacent to C-50 (Figure 23).

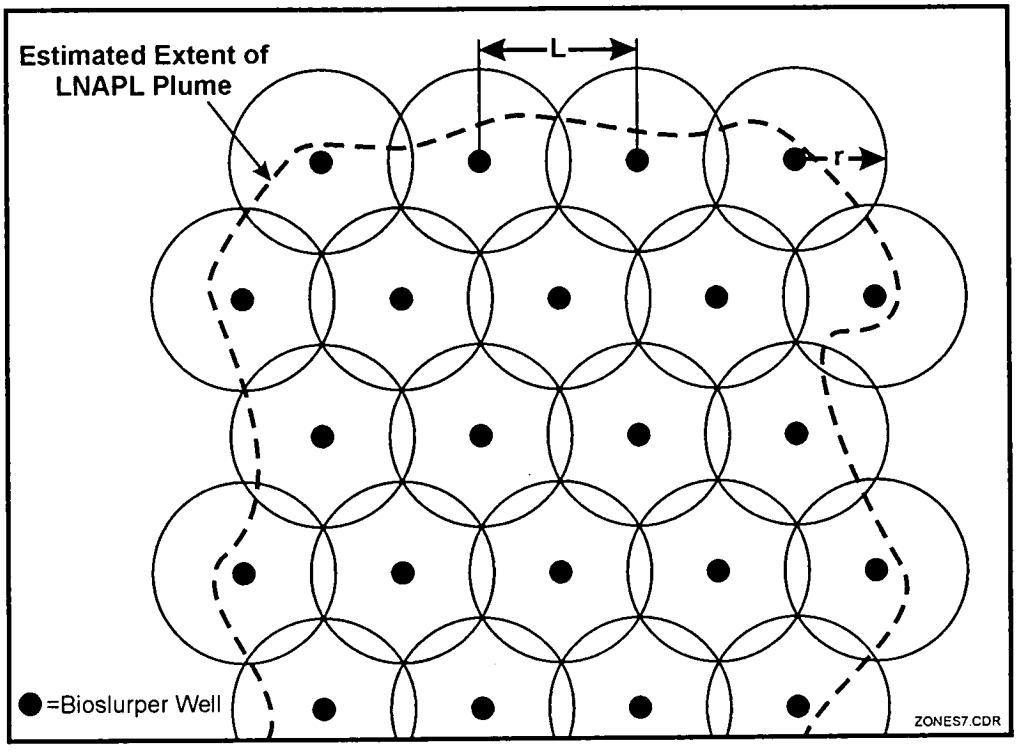

Figure 22. Diagram of Generic Extraction Well Layout

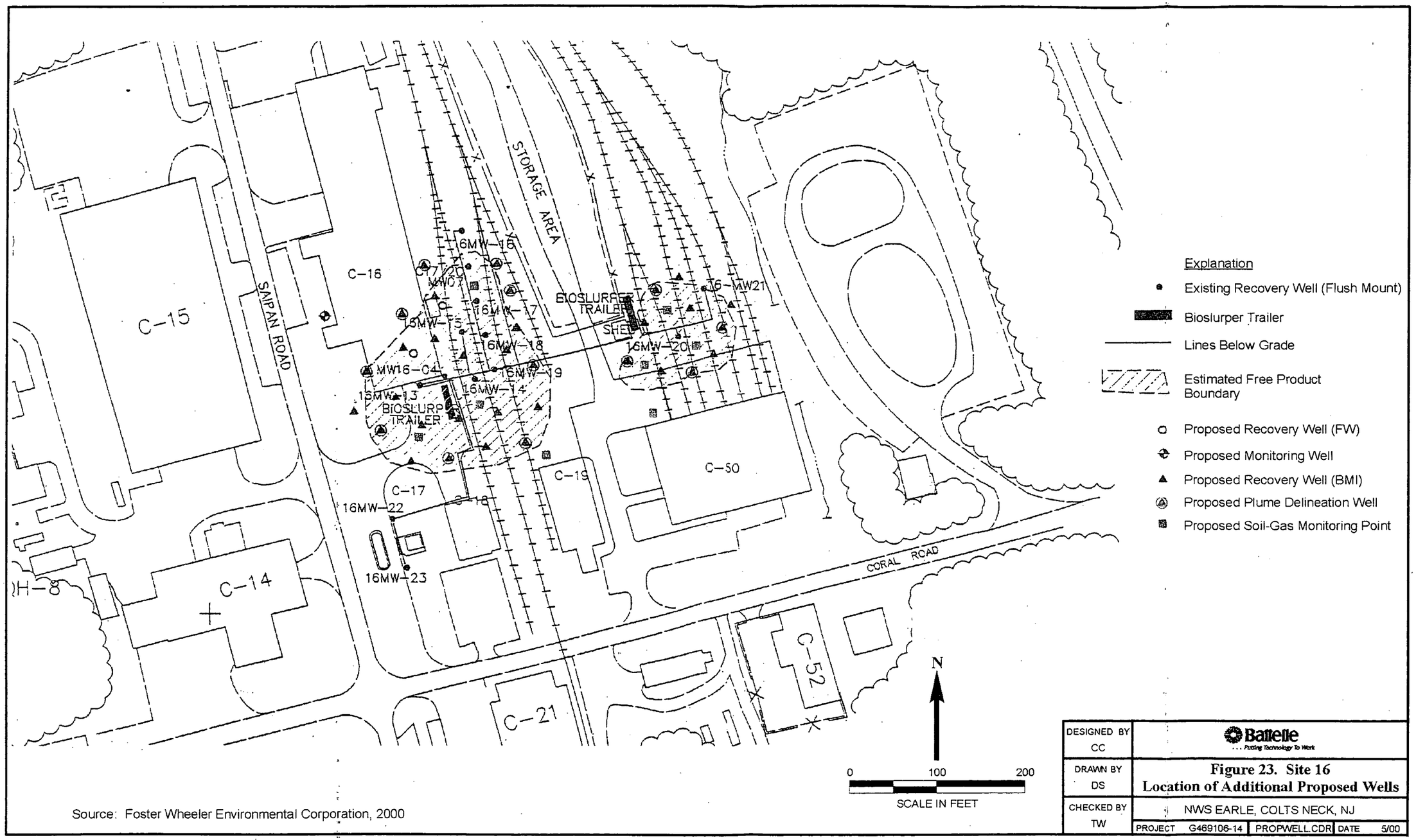

Figure 23. Recommended Locations for Additional Wells and Soil-Gas Monitoring Points

The recommendation to install 33 additional extraction wells is based on the current understanding of the LNAPL plume size and an estimate of radius of influence provided by Foster Wheeler. However, Battelle believes that the LNAPL plume is poorly delineated due to the inadequate number of wells at the site. Therefore, it is recommended that a total of 13 wells first be installed: 9 wells in the plume adjacent to C-16, and 4 wells in the plume located adjacent to C-50. The locations of the wells are shown in Figure 23. Product thickness data collected from these 13 wells can be used to better delineate the plume and ascertain if additional wells will be required.

The plume delineation/extraction wells may be constructed of either 2- or 4-inch-diameter PVC casing. Care should be taken to ensure that the screened interval of the wells encompasses seasonal changes in the water table elevation. Based on historical groundwater fluctuation data, it is recommended that the wells be screened from approximately 4.75 to 12.75 ft bgs.

4.2.2 Drop Tube Placement. The openings of the drop tubes in the extraction wells have been placed at the top of the LNAPL layer (Heffron, 2000). Typically, bioslurper drop tubes are placed at the LNAPL/water interface in the well. Experience at other sites indicates that placing the drop tube opening above the interface can cause mounding of the groundwater table. The locally mounded water table saturates the pores with water, which then can obstruct the flow of LNAPL into the well by lowering the relative permeability of the formation to LNAPL. The effect of this situation is reduced LNAPL extraction rates. A discussion of relative permeability can be found in Domenico and Schwartz (1990).

It is recommended that the drop tubes inside the extraction wells be located at the oil/water interface. The oil/water interface should be measured inside each of the extraction wells after the system has been shut down for several days. The drop tubes then can be set at the interface. Changes in groundwater table elevation will necessitate that the location of the oil/water interface be remeasured and the drop tube be repositioned about every two weeks.

4.2.3 Soil-Gas Monitoring Points. At Site 16F, the water table has been observed to fluctuate from approximately 4.75 to 12.75 ft bgs. As operation of the bioslurper will not cause a drawdown of the water table, the monitoring points should be installed based on the static water levels. Three screens should be sufficient for this interval, with the screens placed from 4.5 to 5, 7 to 7.5, and 9.5 to 10 ft bgs. Based upon current estimates of the extent of the LNAPL plume, approximately eight additional monitoring points should be installed. This will bring the total number of monitoring points at the site to 11, including the three monitoring points installed during the pilot test. Recommended locations of the eight additional monitoring points are shown on Figure 23. These locations are approximate, and can be modified based on field conditions. The locations of the new points also will depend on the location of the existing points from the pilot test, which do not appear on any of the site maps included in the Foster Wheeler reports. Soil-gas samples also may be collected from existing monitoring wells, but these will not typically allow sampling at discrete depths.

4.2.4 Oil/Water Separator. The existing OWS should be replaced with one that is constructed with a weir instead of a skimmer tube. The LNAPL and floating solids will flow over the weir as opposed to entering the relatively small openings in the skimmer tube. This will reduce the potential for fouling. For easy cleaning, the system should be designed with a valve at the outlet of the OWS. The outlet should be closed periodically to raise the water level in the OWS to force the LNAPL and floating solids over the weir into the LNAPL collection chamber.

4.2.5 Off-Gas Treatment. Sufficient data were not available to evaluate the necessity of the off-gas treatment system at the time this document was prepared. The original air discharge permit requires that less than 0.035 lb/hr of total volatile organics (TVOs) be discharged to the atmosphere and that the

concentration of TVOs must remain below 27 ppm. Foster Wheeler has indicated that revised permits were applied for and received that raised the air discharge limit for the bioslurper systems. Battelle was not able to obtain copies of the revised permits from Foster Wheeler by the time that this document was prepared. To determine if off-gas treatment should be continued, biweekly influent and effluent vapor samples should be collected from the treatment system while operating continuously for three months and should be analyzed for TVOs. If concentrations and mass loadings remain below regulatory limits, then off-gas treatment should be discontinued.

4.2.6 Alarm Modification. The programming for the alarm system must be modified to notify the Fire Department only if the sump alarm is activated. The programming can be easily modified with the ProView™ software that is used to control the operation of the system. Procedures may be found in the manufacturers literature which is included as an appendix to the operations and maintenance manual for the site (Foster Wheeler, 2000).

4.2.7 Heat Exchangers. It is recommended that an anti-scaling agent be added to the seal water inside the seal water tank. This agent will help prevent the tubes inside the heat exchanger from becoming fouled with iron and other metal precipitates. Foster Wheeler has tested the use of the chemical addititive, FeREMEDE™, to reduce iron precipitation and flocculant formation in the OWS. It was successful but was discontinued after one month because the increased cost offset the benefit of the treatment chemical. However, it is anticipated that only small doses will be required for this application. A sample of the seal water, along with flowrate and temperature information, can be forwarded to the chemical vendor for dosing recommendations.

4.2.8 Continuous System Operation. Continuous operation of the bioslurper system is necessary to effectively remove the free-product in the area around the extraction wells. Frequent interruptions and/or inefficient operation disrupts active free-product migration toward the well. The current operational practice delays site closeout and can result in the release of more COCs to the groundwater, thereby resulting in elevated remediation costs (Section 5.0). It is recommended that the system operational time be increased from an average of 10% to over 70%.

4.3 Water Treatment System Evaluation and Treatability Testing.

The water treatment system should be modified in an effort to reduce operating costs. Based on the contaminant loading data and costs described in Sections 3.5.3 and 5.0, two alternative water treatment systems consisting of either a settling tank(s) installed upstream of the clay media or a chemical treatment/dissolved air flotation (DAF) system should be evaluated for implementation at Site 16F. The settling tank(s) operate by providing residence time to allow emulsified oil to separate from the process water. The oil floats to the top of the tank and is removed by a floating skimmer pump or similar device. The effluent water will have a reduced concentration of hydrocarbons. Hence, loadings will be reduced on the clay; the clay will last longer thereby reducing replacement costs. The chemical treatment/DAF system requires the addition of a coagulant (ie., ferric sulfate, alum), sodium hydroxide to control pH, and a flocculating polymer. Coagulation is performed in the first stage of a two-stage tank by mixing the coagulant and sodium hydroxide into the process water. The water then enters the second stage where the polymer is mixed into the water. The treated water then flows into a DAF system where the flocs are suspended by microscopic air bubbles and are removed from the process water stream.

Prior to making any changes to the system, the cost and performance of the water treatment system must be further evaluated. The inconsistent operation and resulting wide range of TPH concentrations in the influent and effluent streams make it difficult to ascertain the performance of the treatment system in relation to the operating cost. Additional data are required to accurately determine both the cost and performance of the treatment system. The system should be operated continuously for

approximately one month to generate such data. Inlet and outlet water samples should be collected twice a week and analyzed for TPH to determine mass loading into the clay. It is important to note if the concentrations are decreasing over time, remain consistent, or continue to be erratic. This information will assist in the selection of an appropriate water treatment technology.

During the 1-month continuous operation of the treatment system, treatability testing must be performed using water samples collected from the bioslurper system. Treatibility testing for a chemical treatment/DAF system should evaluate parameters such as:

- The best type of coagulant and flocculant to use.
- Chemical dosage rates.
- Volume of sludge generated per volume of water treated.
- Composition of sludge. Percent oil, solids, and water will affect disposal costs. Data should be collected to confirm that the sludge would be disposed of as a nonhazarous waste.
- Required residence time.

In the case of the settling tank system, a bench-scale study must be performed to determine the residence time necessary to provide adequate separation and to determine the impact of the reduced hydrocarbon concentrations on the operating cost. Results vary considerably, and are greatly affected by site-specific operating conditions. Results of the bench-scale study can be used to calculate the impact on the water treatment operating costs. Figure 14 was generated using the Excel™ treatment model discussed in Section 3.5.3, and shows how the operating cost associated with the clay and carbon would be reduced as the influent concentration to the clay is reduced. It is assumed that the quantity of clay used and that the clay is replaced frequently enough to maintain the influent concentration to the GAC at 30 ppm. Results indicate that the monthly operating cost of the clay/carbon treatment can be reduced by 2/3 if the inlet TPH concentration can be reduced from 1,500 ppm to 500 ppm.

4.4 Monitoring

The monitoring program must contain procedures for collecting the data necessary to eventually justify that the project milestones and endpoints have been met. It also must provide information to assess if the bioslurper system is operating in the most cost-effective manner. In some cases, changing site conditions may require design changes during the remediation process. Long-term monitoring applies to both the site and the bioslurper system itself. Long-term monitoring of the bioslurper system includes collecting data to quantify hydrocarbon recovery as well as operational parameters indicating the efficiency of the system. Generic log sheets used by Battelle to monitor bioslurper systems are included in Appendix A.

To determine the mass of hydrocarbons removed by the bioslurper, recovery rates must be measured in several phases. The recovery of free-phase LNAPL is generally the main source of removal; however, dissolved-phase hydrocarbons may be a significant source of hydrocarbon removal at some sites. The mass of hydrocarbons removed in the dissolved phase typically is determined by monthly sampling of the aqueous effluent for contaminant concentrations. These concentrations along with the process water flowrate are used to calculate the hydrocarbon removal rate. A similar method is used to calculate the mass removed in the vapor phase. A fourth method of hydrocarbon removal is through biodegradation. The biodegradation rate is typically determined by periodically performing in situ respiration tests during the remediation as described in detail in the *Soil Bioventing: Principles and Practice* manual (Leeson and Hinchee, 1997).

Operational parameters that must be monitored during operation include vapor and liquid recovery rates and vacuum levels. These parameters can be used to determine if the bioslurper is operating properly. A decrease in the vacuum achieved by the bioslurper can indicate that the LRP is in need of repair. Low vacuum in the manifold or at the extraction wells may also indicate a leak in the system. Valves should be installed in the system to allow isolation of various portions of the system to test for leaks or other vacuum-related problems. Monitoring of vapor and liquid flow rates allow the operator to observe changes in the effectiveness of the system, and also allow calculation of contaminant recovery rates as discussed above, both for the purpose of quantifying mass removal and for potential modification of the effluent treatment systems.

Important information such as the total mass of hydrocarbons removed from the site, the volume of oil remaining thickness in the extraction wells, distribution of oil in the subsurface, free product recovery as a function of cost, and operating time should also be included in the operation reports. Figures generated using operational data that Battelle has collected at other bioslurper sites are included in Appendix B.

Because the bioslurper system is principally a tool for product recovery, a groundwater monitoring program at the site will typically continue after source removal and bioslurper operation are complete. Dissolved-phase monitoring at a site is pertinent to the operation of a bioslurper system, because the decision to cease source removal may be based on the efficiency of biological, physical, and chemical processes in naturally attenuating the dissolved hydrocarbon plume. If it can be shown through sustained groundwater monitoring that the dissolved contaminant plume is stable or receding, or that potential receptors will remain unaffected, then it may be possible to complete product recovery for source removal. Therefore, groundwater monitoring should provide adequate data on the status of the dissolved plume and to assess the efficiency of natural attenuation processes.

Section 5.0: COST ANALYSIS

Costs to implement the recommendations for bioslurper optimization that were discussed in Section 4.0 are listed in Table 2. The capital and/or O&M costs to implement each recommendation were estimated using cost information provided by Foster Wheeler and supplementing that information with catalog prices or quotes and engineering judgement. Actual costs that will be incurred may deviate depending on site-specific requirements and regulations imposed by the Office of the Resident Officer in Charge of Construction (ROICC); regulatory requirements (e.g., frequency of sampling); and labor rates, overheads, and fees associated with the contractor and his subcontractors. Travel costs are not included in this estimate.

Table 2. Summary of Recommendations for Bioslurper Optimization and Associated Costs

Recommendation	Cost Elements	Cost
Install 33 additional wells and 8 soil-gas monitoring points, and reduce spacing between wells	• Drill rig and crew • Well and soil-gas monitoring point materials • Well development • Permitting • Disposal of drill cuttings • Labor (geologist, technician)	$106,000
Expand manifolds to include new extraction wells	• Trenching, pipe installation, resurfacing, and materials	$292,500[(a)]
Install new OWS and additional bag filter at each unit	• 2 OWSs • Installation labor (engineer, technician) • Assumes cargo box does not require disassembly to replace OWS	$18,000
Set drop tubes at oil/water interface, and reset every 2 weeks	• 8 hrs/month labor	$400
Collect water treatability test data	• Sampling (labor and analytical costs) • Reporting (labor)	$10,000
Select and install water treatment technology	• Design and installation labor • Float switches • Transfer pumps • Settling tank or chemical treatment/DAF unit and associated equipment • Does not include secondary containment, explosion-proof materials	Settling tank: $9,500 Chemical treatment/DAF system: $112,000
Discontinue vapor treatment	• None	$0
Reprogram the alarm controller	• 2 to 8 hrs labor	$100 to $400
Perform routine maintenance of heat exchanger	• 1 hr/month labor • Anti-scaling compound	$600/year

(a) Assumes 1,500 linear feet. This cost is based on the cost of $195,000 to install the existing manifold (Foster Wheeler, 2000)

A simplified life cycle cost-savings analysis was performed to calculate the savings resulting from lowering the cost of unit effluent treatment and reducing the time required to complete source removal. To perform the cost-savings analysis for system optimization, the additional capital costs and annual O&M costs were estimated for the following three options:

- **Option 1:** No system modifications are made, except for the installation of additional wells and associated manifolds to cover areas outside the radius of influence of the existing

wells. The bioslurper system is operated intermittently similar to the current practice at the site. During the first year of operation Unit #1 and Unit #2 operated for 11% and 4% of the year, respectively. This option assumes that the system will be operated for 15% of the year.

- **Option 2:** All recommendations to optimize bioslurper operation are implemented, including well and manifold installation. The bioslurper is operated continuously, using settling tank, clay, and GAC treatment.

- **Option 3:** All recommendations to optimize bioslurper operation are implemented, including well and manifold installation. The bioslurper system is operated continuously, using a chemical treatment/DAF system.

The capital costs for Options 1, 2, and 3 are assumed to be $398,000, $437,000, and $539,000 respectively. The capital cost for Option 1 includes only the cost to install the 33 additional extraction wells, 8 soil gas monitoring points, and 1,500 linear feet of manifold. This number was scaled-up using a cost of $195,000 provided by Foster Wheeler for installation of the existing manifold. The capital cost for Option 2 includes the cost of installing a settling tank, and the capital cost of Option 3 includes the cost of installing a chemical treatment/DAF system. The capital costs for both Options 2 and 3 include the cost to implement the remaining system optimization recommendations listed in Table 2.

The annual operating costs for each of the treatment options are summarized in Table 3. The costs are broken down into those associated with off-gas treatment, water treatment, off-gas and water sampling and analysis, O&M labor (at $50/hr), and miscellaneous expenses (including travel, telephone, and various material costs).

Table 3. Annual O&M Costs for Options 1, 2, and 3

Cost Element	Option 1	Option 2	Option 3
Off-Gas Treatment O&M	$13,750	$0	$0
Water Treatment O&M[(a)]	$68,000	$146,700 [(b)]	$78,300 [(b)]
Off-Gas and Water Sampling and Analysis	$27,500	$27,500	$27,500
O&M Labor	$80,000	$106,600 [(c)]	$106,500[(c)]
Miscellaneous	$15,700	$15,700	$15,700
Total Annual O&M	**$205,000**	**$296,500**	**$228,000**

(a) Includes materials, labor and disposal. The cost to periodically clean out the OWSs also is included ($8,000/year), and is assumed to be the same for all three options.
(b) 8 gpm flowrate from each unit.
(c) Assumes that an additional 10 hrs/week are required to operate system continuously.

The cost of off-gas treatment for Option 1 was estimated using costs incurred during the first year of O&M (Foster Wheeler, 2000). For Options 2 and 3, it was assumed that off-gas treatment has been eliminated; hence, the treatment cost is zero. The cost of water treatment for Option 1 is based on data provided by Foster Wheeler, which reported that approximately 581,000 gallons of water was extracted during the first year of operation. During that period, the cost of clay and carbon changeout was approximately $60,000 (Foster Wheeler, 2000), which represents an average unit cost of $103 per 1,000 gal of process water. The cost of water treatment for Option 2 was estimated assuming that the average effluent TPH concentrations from the settling tank and from the clay vessel are maintained at 250 and 15 ppm, respectively. The assumptions used in estimating the cost of clay and carbon changeout are described in Section 3.5.3. In addition, it is assumed one hr/week labor will be required to skim accumulated oil in the settling tank. The chemical treatment/DAF system eliminates the use of clay, but

likely will require GAC for final polishing. The following assumptions were used to estimate the cost of water treatment using chemical treatment/DAF:

- The TPH concentration in the influent to the GAC is 15 ppm
- The dosages for chemical treatment are 300 ppm for ferric dosage and 2 ppm for polymer dosage.
- Sludge produced (approximately 0.003 gal sludge/gal water) is non-hazardous and the disposal cost is $0.65/gal.

Approximately 10 hrs/week additional labor will be required to operate the system. The miscellaneous costs and analytical costs were estimated based on data provided by Foster Wheeler (2000).

The option that involves the lowest estimated annual operating costs is Option 1. However, because Option 1 requires the bioslurper system to not be operational for a significant period of time (i.e., twice as long or longer), the time to complete source removal would be much greater with Option 1 than with either Option 2 or 3. For example, if it is assumed that source removal would be complete after two years by implementing either Option 2 or 3, then the total operating cost would be $593,000 and $456,000, respectively, for those treatment options. For Option 1 in this example, even if source removal would only take four years, the total operating cost would increase to $820,000, which exceeds the cost of either of the other two options by more than $200,000.

The estimated annual operating cost to treat the bioslurper process water using a chemical treatment/DAF system is less than using a settling tank and hydrophobic clay; however, the capital cost to install the settling tank is much less than the chemical treatment system (about $9,500 compared to $112,000). Before making a decision on whether to implement optimization Option 2 or 3 at Site 16F, it will be necessary to perform some bench-scale treatibility tests on the aqueous stream (Section 4.3). The resulting performance data then can be used to validate these costs and implement the most cost-effective technology at Site 16F.

Section 6.0 REFERENCES

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APPENDIX A

Shutdown Log Sheet
North Trailer, NS Mayport

Date	Time	LRP timer reading (hours)	Reason for Shutdown	Corrective Action

Shutdown Log Sheet
South Trailer, NS Mayport

Date	Time	LRP timer reading (hours)	Reason for Shutdown	Corrective Action

Groundwater Sampling Log Sheet
NS Mayport

Date	Time	LRP timer reading (hours)	Water Totalizer Reading (gallons)	Sample ID	Sampling Location	Analysis Requested	Sampler's Initials

Off-gas Sampling Log Sheet
NS Mayport

Date	Time	LRP timer reading (hours)	Off-gas Flowrate (scfm)	Sample ID	Sampling Location	Analysis Requested	Sampler's Initials

Soil-Gas Monitoring
Sludge Beds

Dat :_____ Field Personnel:_____

Monitoring Point ID	Oxygen	Carbon Dioxide	TPH		Monitoring Point ID	Oxygen	Carbon Dioxide	TPH
MP1-G					MP1-R			
MP2-G					MP2-R			
MP3-G					MP3-R			
MP4-G					MP4-R			
MP5-G					MP5-R			
MP6-G					MP6-R			
MP7-G					MP7-R			
MP8-G					MP8-R			
MP9-G					MP9-R			
MP10-G					MP10-R			
MP11-G					MP11-R			
MP12-G					MP12-R			
MP13-G					MP13-R			
MP14-G					MP14-R			
MP15-G					MP15-R			
MP17-G					MP17-R			
MP18-G					MP18-R			
MP19-G					MP19-R			

*Measurements are to be taken monthly

Date:_____ Field Personnel:_____

Well	Well head vacuum prior to closing extraction well (in H2O)	Date extraction well was closed	Depth to Product (ft fromTOC)	Depth to H_2O (ft from TOC)	Comments/Visual Observations
EW1					
EW3					
EW7					
EW9					
EW10					
EW11					
EW14					
EW15					
EW17					
EW19					
EW20					
EW24					
EW25					
EW27					
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EW132					
EW133					
EW134					
EW135					
EW136					
EW137					
EW138					
EW139					

EW140					
EW141					
Sump 1					
Sump 2					
Sump 3					
Sump 4					
Sump 5					
TW4					
TW1A					
TW2A					
TW3A					
TW8					
TW10					
TW11					
MW15I					
MW15S					
MW16S					
MW11S					
MW7S					

* LNAPL measurements are to be collected monthly
Toc = Top of Casing

Full-Scale Bioslurper System, North Trailer
Operations Data Sheet
Naval Station Mayport

Date			
Time of Day			
LRP Timer (hours)			
Equilization Tank Vacuum (in Hg)			
LRP Vacuum (in Hg)			
Water Totalizer Reading (gal)			
Fuel Recovered Since Last Measurement (gallons)			
Total Fuel Recovered (Gallons)			
LRP Stack Temperature (°F)			
Seal Water Temperature (°F)			
Oxygen in LRP Stack Gas (%)			
Carbon Dioxide in LRP Stack Gas (%)			
Total Petroleum Hydrocarbons in Stack Gas (ppm)			
Off-Gas Flowrate (scfm)			
Number of wells operating			

Notes/Comments

Full-Scale Bioslurper System, South Trailer
Operations Data Sheet
Naval Station Mayport

Date			
Time of Day			
LRP Timer (hours)			
Equilization Tank Vacuum (in Hg)			
LRP Vacuum (in Hg)			
Water Totalizer Reading (gal)			
Fuel Recovered Since Last Measurement (gallons)			
Total Fuel Recovered (Gallons)			
LRP Stack Temperature (°F)			
Seal Water Temperature (°F)			
Oxygen in LRP Stack Gas (%)			
Carbon Dioxide in LRP Stack Gas (%)			
Total Petroleum Hydrocarbons in Stack Gas (ppm)			
Off-Gas Flowrate (scfm)			
Number of wells operating			

Notes/Comments

Discharge Record Sheet
AST 1, NS Mayport

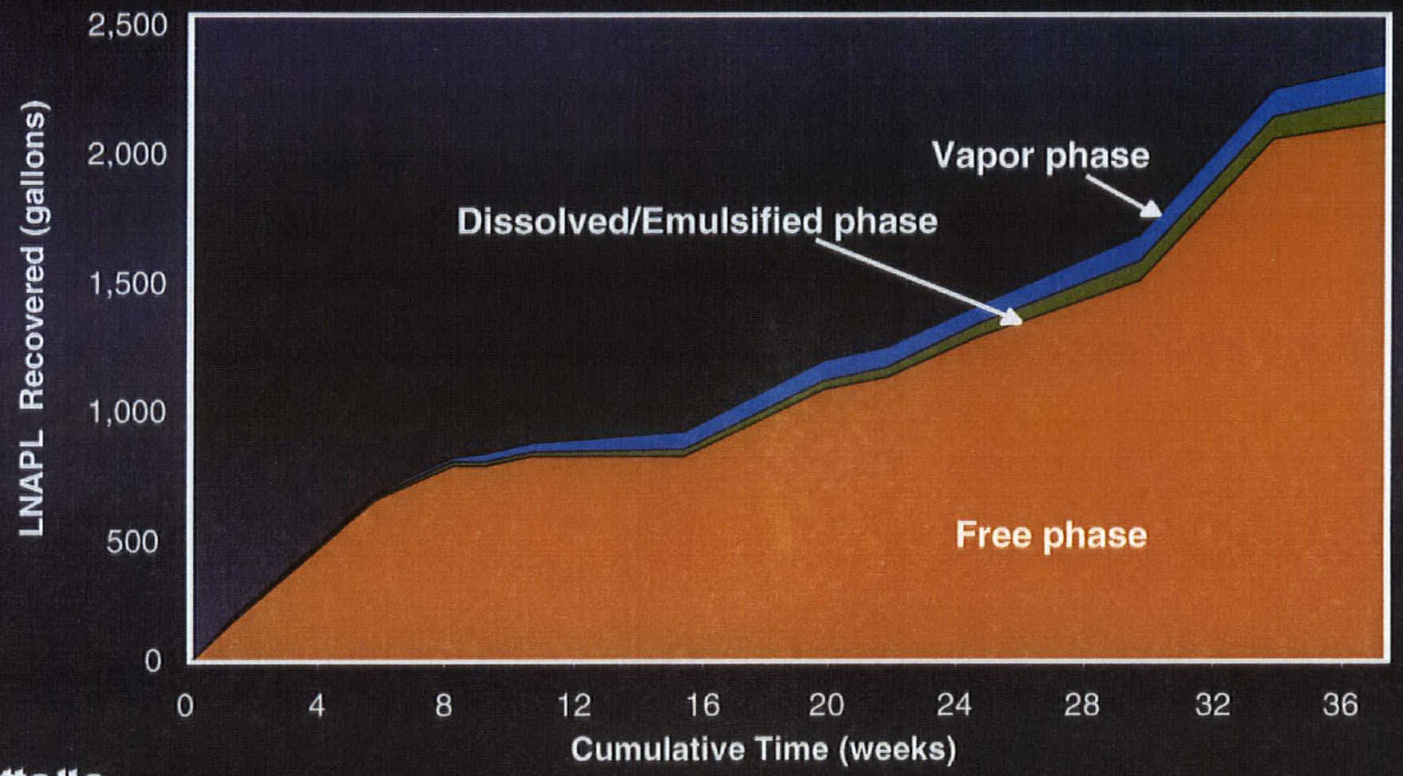
Date	Depth to Product Before Discharge (ft)	Depth to H_2O Before Discharge (ft)	Depth to Product After Discharge (ft)	Depth to H_2O After Discharge (ft)	Fuel Recovered (gallons)	Groundwater Discharge (gallons)

Discharge Record Sheet
AST 2, NS Mayport

Date	Depth to Product Before Discharge (ft)	Depth to H_2O Before Discharge (ft)	Depth to Product After Discharge (ft)	Depth to H_2O After Discharge (ft)	Fuel Recovered (gallons)	Groundwater Discharge (gallons)

APPENDIX B

Product Recovery
Former Refinery



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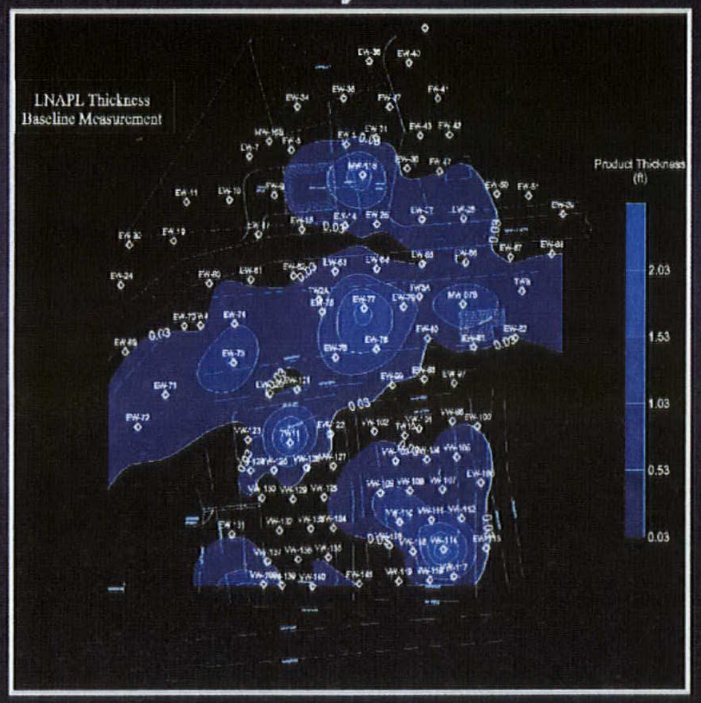
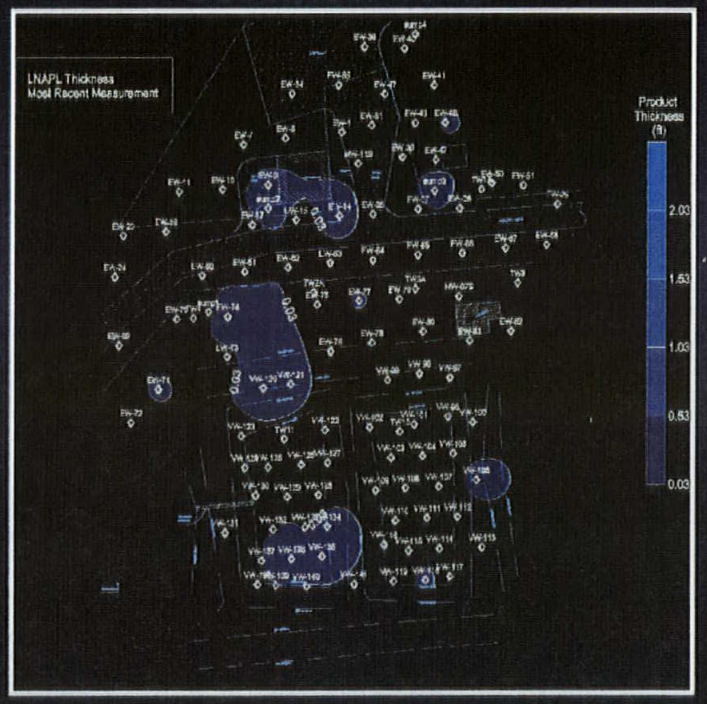
Free Product Thickness Monitoring

Sludge Drying Bed Area

January 1998



December 1999



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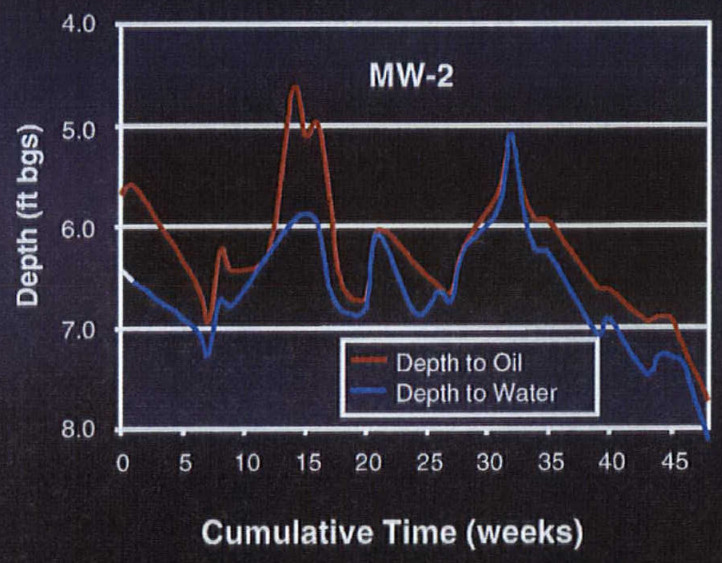
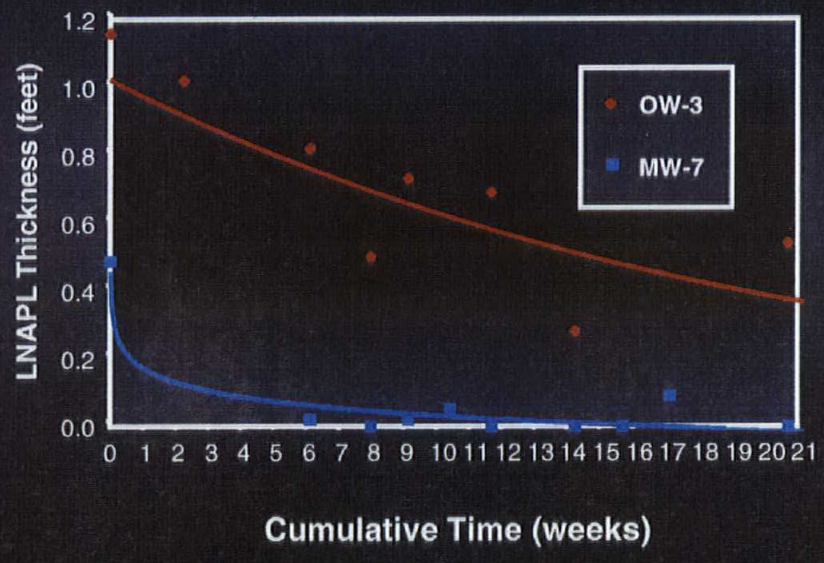
Free Product Thickness Monitoring

Fire Fighting Training Area





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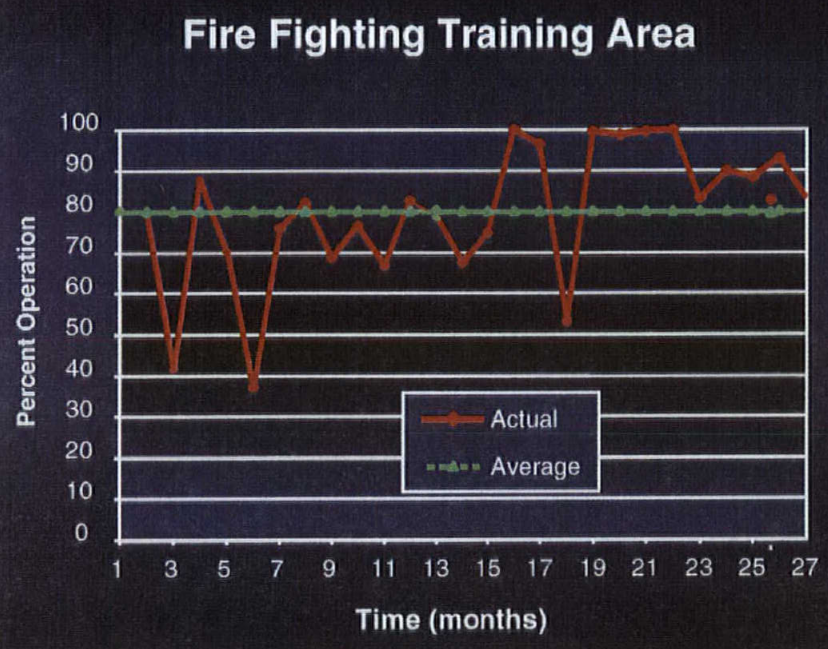
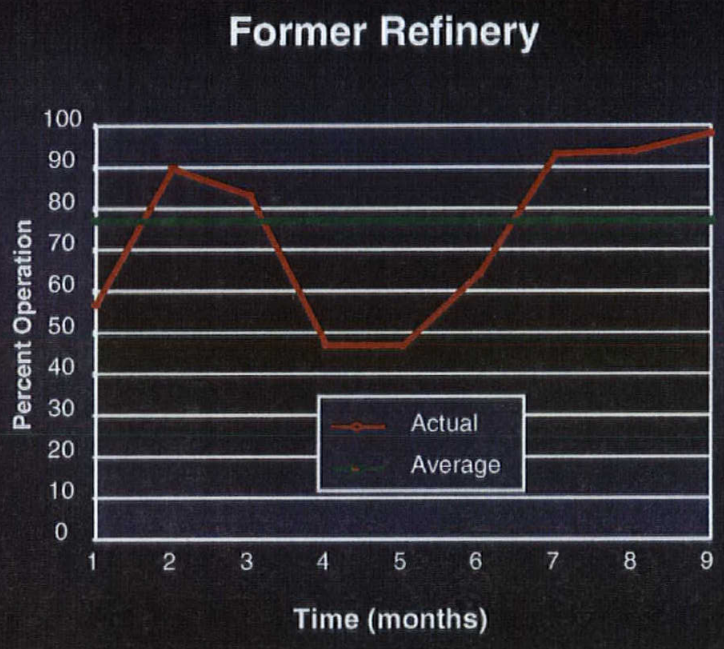
System Operational Time





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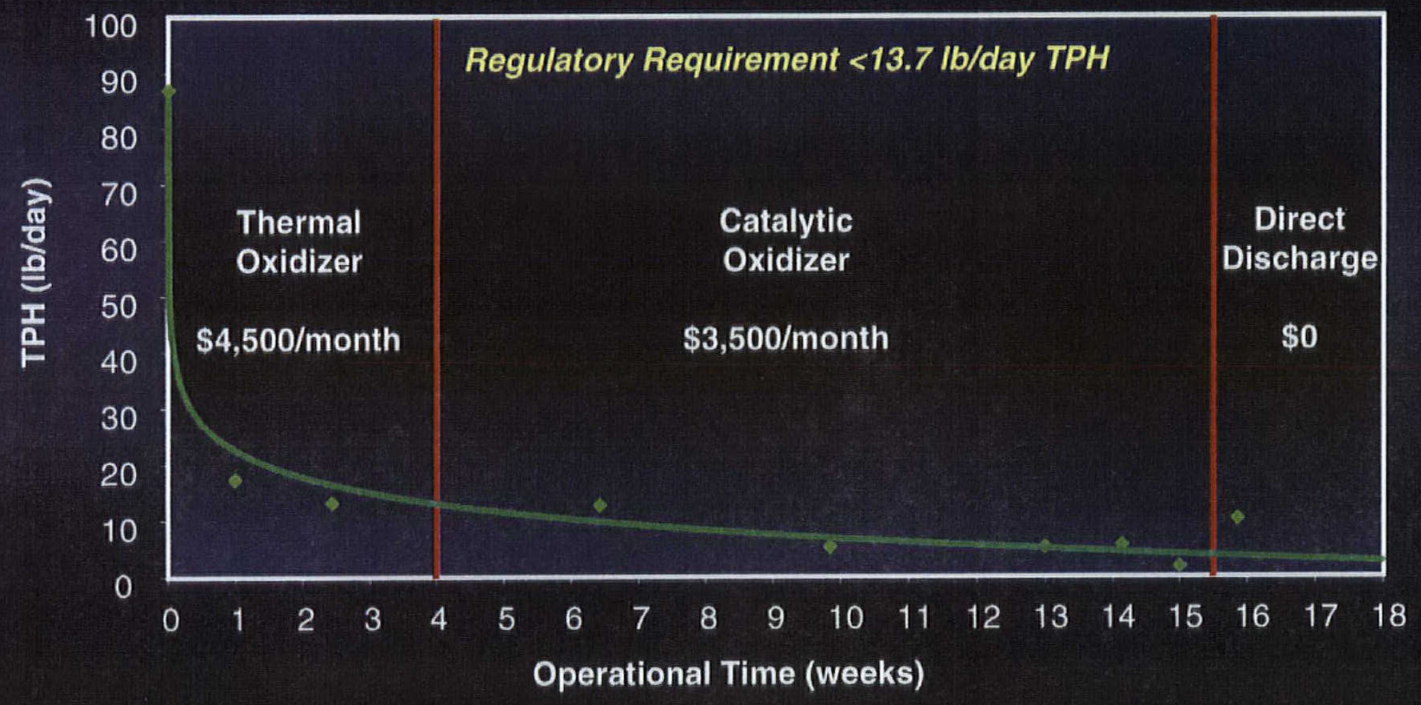
Off-Gas Treatment Optimization
Fire Fighting Training Area



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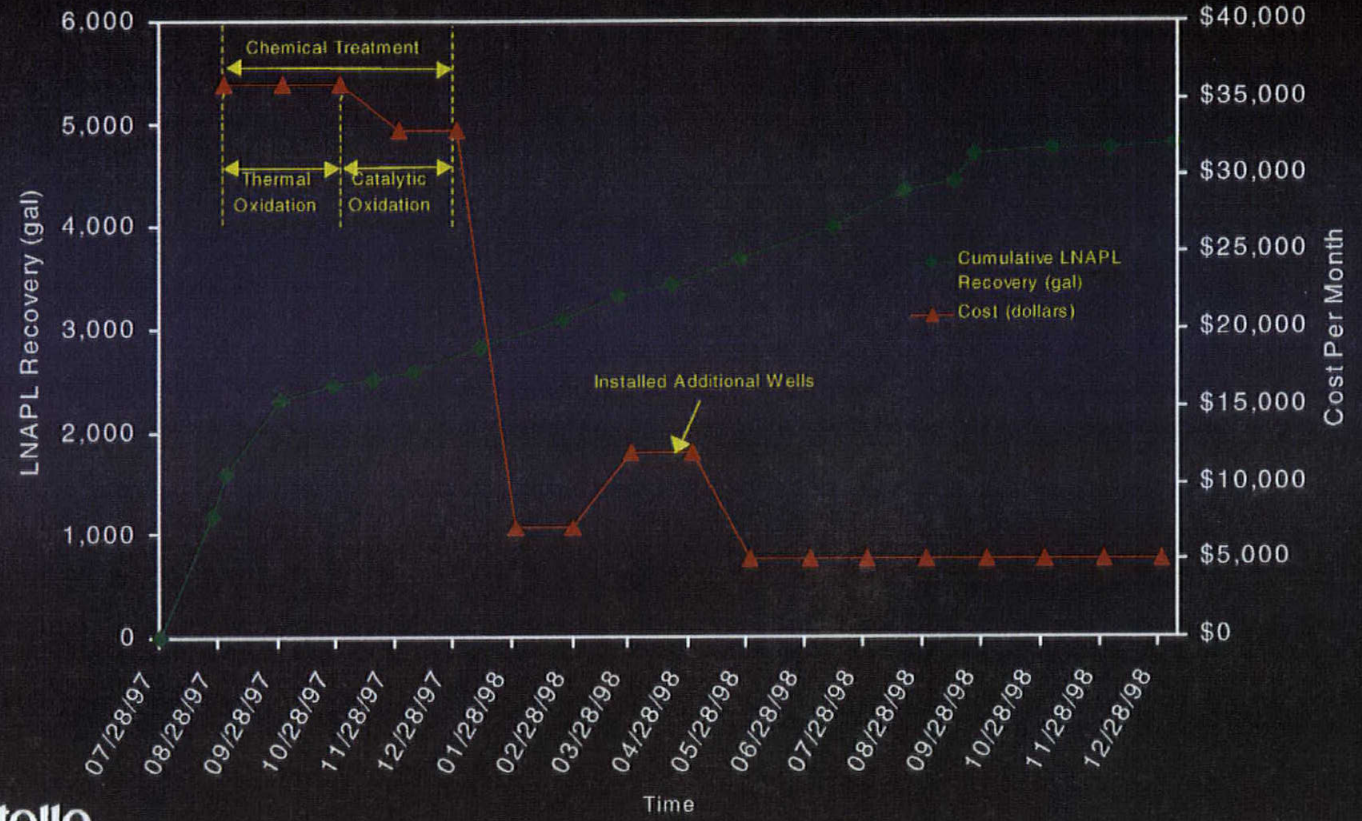
Cost and Performance



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