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Preliminary Site Characterization Summary and Engineering Evaluation/Cost Analysis for Site 2—New Fuel Farm, Naval Air Station Fallon, Fallon, Nevada

T. A. Cronk
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ORNL/TM-11886

Health and Safety Research Division

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CONTENTS

FIGURES v
TABLES vii
ABSTRACT xi

INTRODUCTION 1
BACKGROUND 2
NATURE OF PROBLEM 4
SYNOPSIS OF ENVIRONMENTAL INVESTIGATIONS TO DATE 7
CONTAMINATED MEDIA OF CONCERN 7
Summary of IR Program-Phase II Preliminary Site Characterization 16
Extent and Degree of Contamination 33
ENVIRONMENTAL ASSESSMENT 33
Transport Mechanisms and Migration Pathways 35
Exposure Points and Affected Biota 42
APPLICABLE OR RELEVANT AND APPROPRIATE REQUIREMENTS (ARARs) 42
FREE-PRODUCT REMOVAL ACTIONS 46
GOALS OF FREE-PRODUCT REMOVAL ACTIONS 46
DEVELOPMENT AND EVALUATION OF FREE-PRODUCT REMOVAL TECHNOLOGIES 46
Technologies to Access Free Product 47
Technologies for Free-Product Extraction 50
DEVELOPMENT OF ALTERNATIVES FOR FREE-PRODUCT REMOVAL 57
EVALUATION OF FREE-PRODUCT REMOVAL ALTERNATIVES 58
Individual Alternative Evaluation 58
Collective Evaluation of Free-Product Removal Alternatives 64

RECOMMENDATION OF PREFERRED FREE-PRODUCT REMOVAL ALTERNATIVE 64
CONCLUSIONS AND RECOMMENDATIONS 72
REFERENCES 76
ACRONYMS AND ABBREVIATIONS 78

FIGURES

1 Regional location map of NAS Fallon 3
2 Location map, NAS Fallon.
Group I Sites: Site 2, New Fuel Farm, and Site 4, Transportation Yard 5
3 1988 ERM-West soil-gas survey showing contaminated areas.
Group I Sites: Site 2, New Fuel Farm, Site 4, Transportation Yard 8
4 Location map, ERM-West boreholes and monitoring wells.
Group I Sites: Site 2, New Fuel Farm, Site 4, Transportation Yard 10
5 Nevada Division of Environmental Protection, 1990 sample location map.
Group I Sites: Site 2, New Fuel Farm 14
6 Soil-gas total volatile organic concentrations.
Group I Sites: Site 2, New Fuel Farm, Site 4, Transportation Yard 18
7 In-phase geophysical contour map.
Group I Sites: Site 2, New Fuel Farm, Site 4, Transportation Yard 19
8 Map showing groundwater testholes, contamination source areas, ORNL monitoring wells, and floating-product plumes.
Group I Sites: Site 2, New Fuel Farm, Site 4, Transportation Yard 22

9 Location map, ORNL wells, piezometers, and soil samples. Group I Sites: Site 2, New Fuel Farm, Site 4, Transportation Yard 24
10 Potentiometric surface contour map as determined from geostatistical interpretation based on 20 potentiometric head measurements taken August 1990. Group I Sites: Site 2, New Fuel Farm, Site 4, Transportation Yard 37
11 ERM-West and ORNL monitoring well location map. Group I Sites: Site 2, New Fuel Farm, Site 4, Transportation Yard 38
12 Fence diagram of selected Group I wells 41
13 Location map of interim protective measures. Group I Sites: Site 2, New Fuel Farm, Site 4, Transportation Yard 66
14 Cross section of free-product removal system and detail drawing of concrete extraction manhole 68
15 Cross section of Lower Diagonal No. 1 Drain, containment/gradient control system 71
16 Detail of Lower Diagonal No.1 Drain weir 73

TABLES

1 Groundwater analysis, ERM-West investigation 11
2 Soil analysis, ERM-West investigation 12
3 Soil and groundwater analysis, NDEP investigation 15
4 Site 2 anion and metal analysis, groundwater - ORNL/GJ investigation 25
5 Site 2 water analysis - ORNL/GJ investigation 26
6 Site 2 soil analysis - ORNL/GJ investigation 29
7 Summary of environmental sampling at Site 2 34
8 Hydrological parameters - ORNL/GJ investigation 40

9 Comparative analysis - Technologies to access free product 51
10 Comparative analysis - Free-product extraction technologies 56
11 Comparative analysis - Free-product removal alternatives 65

ABSTRACT

This report addresses subsurface contamination associated with Site 2, the New Fuel Farm at Naval Air Station Fallon (NAS Fallon), Nevada. The report is an integral part of Phase II of the Installation Restoration Program (IR Program) currently underway at the facility.

This report: 1) reviews and assesses environmental information characterizing Site 2; 2) determines if site-characterization information is sufficient to design and evaluate removal actions; and 3) investigates, develops, and describes any removal actions deemed feasible.

Previous environmental investigations at Site 2 indicate the presence of floating product (primarily JP-5) on the water table underlying the facility. While the extent of floating-product plumes has been characterized, the degree of associated soil and groundwater contamination remains uncertain. A comprehensive characterization of soil and groundwater contamination will be completed as the Remedial Investigation/Feasibility Study progresses.

Corrective actions are recommended at this time to remove free-phase floating product. Implementing these removal actions will also provide additional information which will be used to direct further investigations of the extent, mobility, and potential environmental threat from soil and groundwater contaminants at this site.

INTRODUCTION

This characterization summary and removal-action evaluation for Site 2, the New Fuel Farm, has been prepared as part of Phase II of the Installation Restoration Program (IR Program) currently underway at Naval Air Station Fallon (NAS Fallon), Nevada. The IR Program is designed to ensure that Department of Defense (DOD) facilities comply with environmental legislation outlined in the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) of December, 1980, as amended by the Superfund Amendments and Reauthorization Act (SARA) (NEESA 1984).

The IR Program is initiated through a Phase I Preliminary Assessment/Site Inspection (PA/SI). Phase I utilizes employee interviews, site inspections, record searches, and limited analytical testing to determine areas where environmental contamination may be present. Potentially contaminated sites are recommended for inclusion in Phase II, Remedial Investigation/Feasibility Study (RI/FS), where additional analytical testing verifies and determines the extent and magnitude of contamination. Phase II work also includes recommending a preferred remedial alternative through a systematic evaluation of remedial options. Finally, the preferred remedial alternative is implemented in Phase III, Remedial Design/Remedial Action.

When site characterization requires extensive testing, substantial time may lapse before remedial action is implemented. In light of this fact and when deemed appropriate by the Naval Facilities Engineering Command, the Navy has made provisions for implementing removal actions during any phase of the IR Program. The free-product-removal actions developed in this document are being recommended for implementation in this capacity in conjunction with Phase II of the IR Program.

The following sections contain a brief history of operations at NAS Fallon and the history and nature of the subsurface contaminants associated with Site 2. An in-depth discussion of the characterization summary will be presented later in the RI/FS Report.

BACKGROUND

NAS Fallon is approximately six miles southeast of the town of Fallon and sixty miles east of the city of Reno, Nevada (Fig. 1). The facility lies in the central Carson Desert, commonly known as the Lahontan Valley. The climate is semiarid with an average rainfall of 13 cm (5 in.) per year.

Naval Air Station Fallon was originally established as a military facility in 1942, when the Civil Aviation Administration and Army Air Corps constructed four airfields in Nevada as part of the Western Defense Program. In 1943, the Navy assumed control of the still uncompleted facility and on June 10, 1944, Naval Air Auxiliary Station (NAAS) Fallon was commissioned. The newly commissioned facility provided training, servicing, and support to air groups sent to the base for combat training. From 1946 to 1951, NAAS Fallon experienced varying but reduced operational status and was eventually turned over to Churchill County and the Bureau of Indian Service.

In 1951, Fallon was used as an auxiliary landing field for NAS Alameda, California, and on October 1, 1953, NAAS Fallon was re-established. On January 1, 1972, NAAS Fallon was upgraded to its current status of NAS Fallon, which serves primarily as an aircraft weapons delivery and tactical air combat training facility.

Since its inception in 1942, various kinds of environmentally harmful materials have been routinely used and/or disposed of at NAS Fallon. These include jet fuel (JP-4 and JP-5), oil, av-gas, gasoline, antifreeze, hydraulic fluid, solvents, paint, and industrial and municipal garbage. These substances may have been introduced into the environment during aircraft refueling, maintenance, and washing; vehicle maintenance; off-specification fuel disposal; fire training exercises;

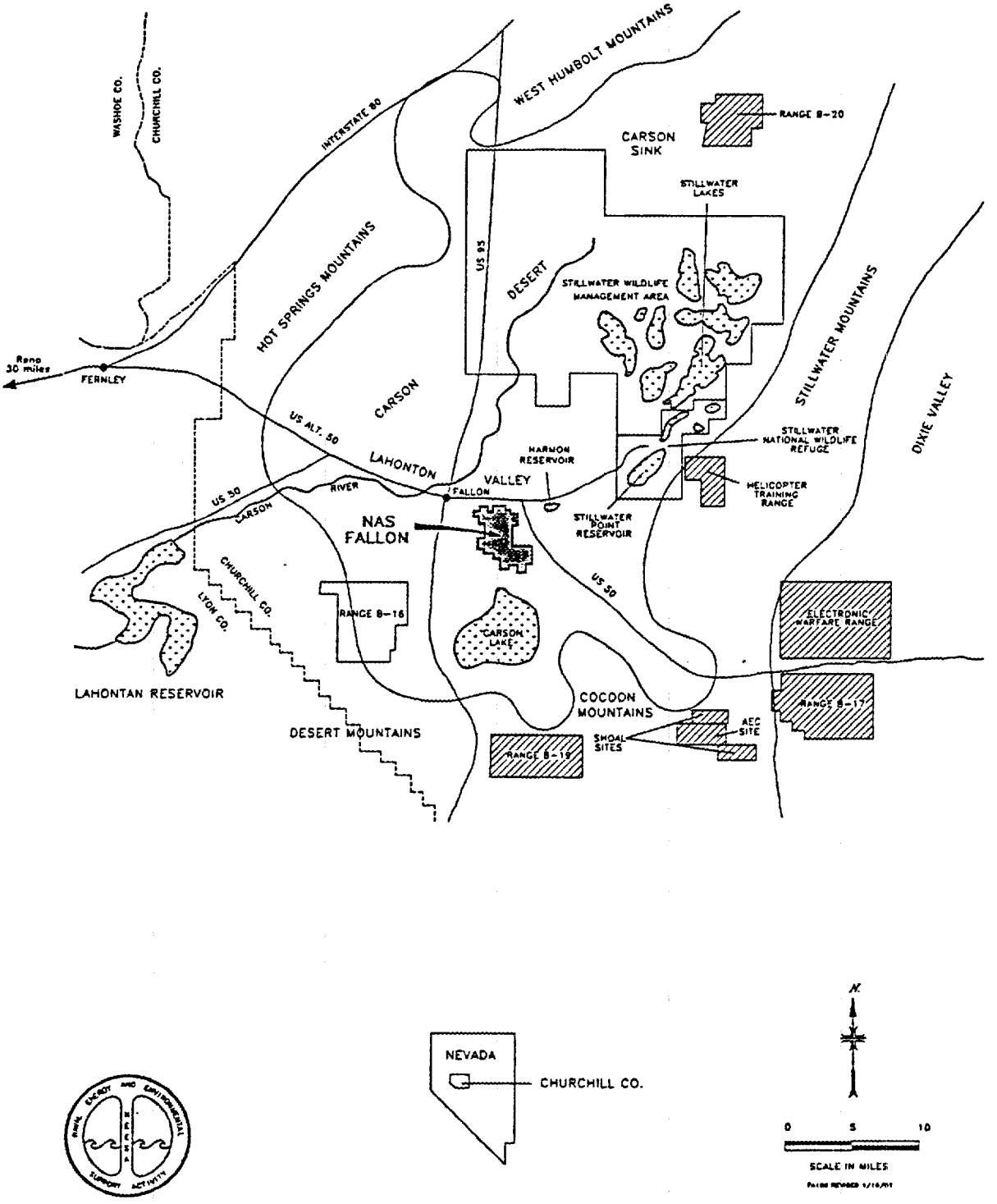


Fig. 1. Regional location map of NAS Fallon.

tank cleaning; sewage disposal; pest and weed control; landfilling; and accidental leaks and spills. Currently, the base actively implements comprehensive waste management practices to control identified environmental pollutants and comply with current federal and state regulations.

NATURE OF PROBLEM

The New Fuel Farm, Site 2, is located in the northwest quarter of the main station of NAS Fallon (Fig. 2). Fuels currently stored at the site include JP-5, AV 100/130 gas, diesel, and mogas (motor vehicle gasoline). Approximately 12,000 m^3 (3,200,000 gal) of JP-5 reside in three underground and two aboveground storage tanks. Two underground AV 100/130 gas tanks have a total storage capacity of 370 m^3 (98,000 gal.) Sixty cubic meters (16,000 gal) of diesel fuel and 45 m^3 (12,000 gal) of mogas are also routinely stored at the fuel farm. The fuel farm's main operations consist of fueling and defueling aircraft and periodic testing of the various fuels stored at the facility.

Past activities at the facility have resulted in public concern and several legal actions against NAS Fallon regarding environmental contamination issues. The following paragraphs discuss the history of environmental concerns associated with Site 2.

On August 26, 1986, the discovery of fuel floating on the water table underlying Site 2 prompted the Nevada Division of Environmental Protection (NDEP) to issue a Finding of Alleged Violation and Order to Comply to NAS Fallon (ORNL/GJ 1989). The NDEP found NAS Fallon in violation of Nevada Regulatory Statutes (NRS) 445.221 which prohibits discharging pollutants without a permit. The Order to Comply required NAS Fallon to submit information on the extent of contamination and to implement a plan to clean up the site subject to the approval of the NDEP.

After an initial effort by base personnel to comply with the Order to Comply, a private consulting firm, ERM-West, was contracted to

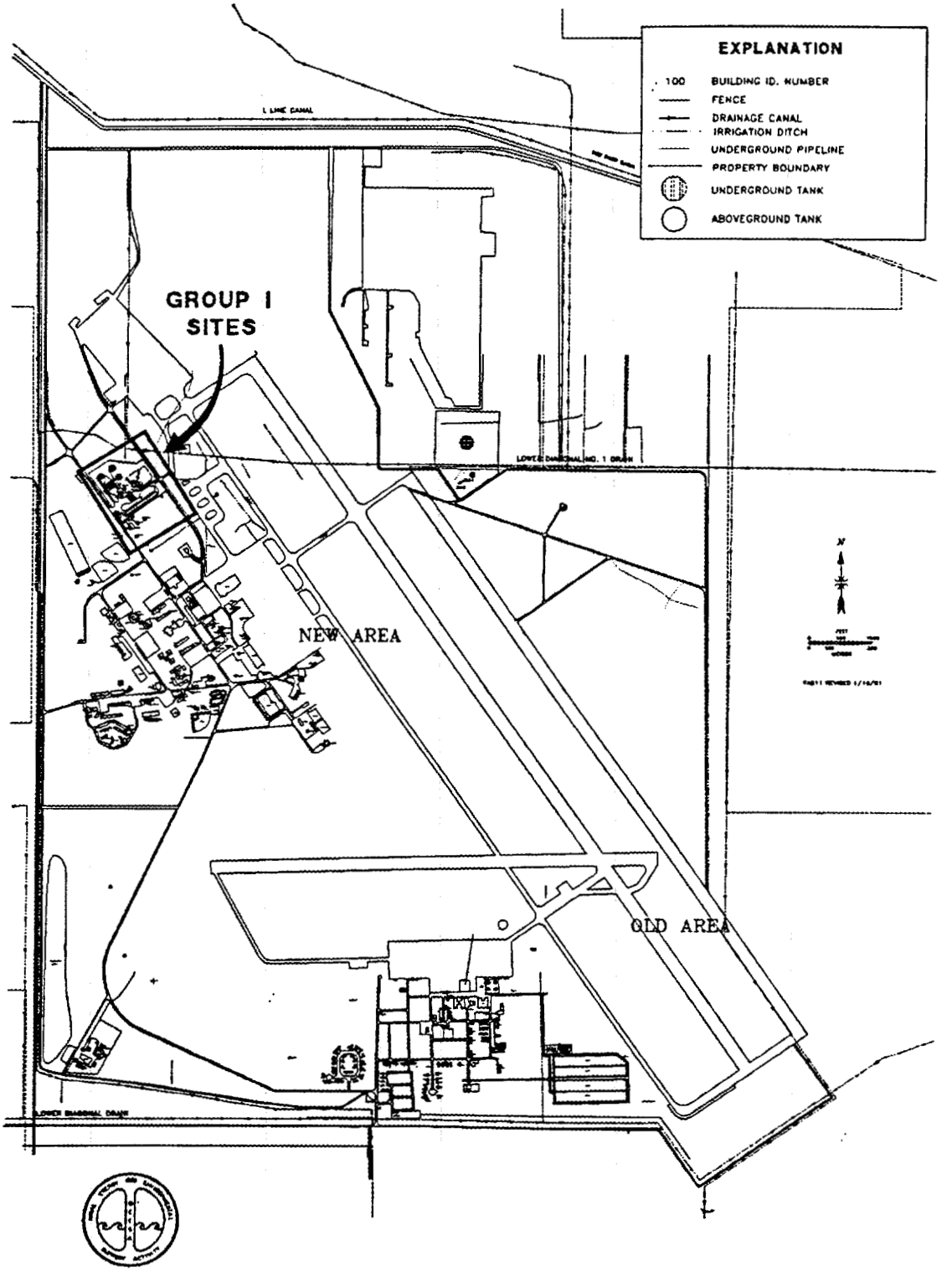


Fig. 2. Location map, NAS Fallon. Group I Sites: Site 2, New Fuel Farm, and Site 4, Transportation Yard.

perform an investigation. ERM-West's soil, soil-gas, and groundwater tests indicated petroleum-hydrocarbon contaminants underlying the facility. Conclusions from the ERM-West investigation included the recommendation that a system be designed and implemented to remove free product (i.e., nonaqueous-phase product) from the underlying water table. NAS Fallon began removing free product from two previously installed wells, but the program was inefficient due to improper well design (ERM-West 1988). The product recovery was discontinued when Phase II of the base-wide IR Program began in September 1988, under the rationale that remediation would be accomplished through interim measures during the IR Program.

Additional legal actions occurred at the New Fuel Farm as Phase II work progressed. In March 1989, a notice of violation from the NDEP resulted in discontinuing use of the fuel farm oil/water separator by NAS Fallon (ORNL/GJ 1989). The oil/water separator remains in place and out of service pending design of additional remedial action at the site. In February 1990, another NDEP action concerned the investigation of an alleged fuel spill in January/February 1988 (NDEP 1990). The investigation concluded that a release of JP-5 jet fuel did occur at the facility on February 22, 1988. The NDEP recommended further investigation into the scope and magnitude of subsurface contamination and that identified environmental problems be remedied. Additional recommendations included leak testing of the fuel storage facilities and associated piping. Leak testing was completed in July 1990.

Presently, Phase II efforts, combined with other environmental investigations (ERM-West 1988; NDEP 1990), indicate free-product petroleum hydrocarbon (primarily JP-5 jet fuel) floating on the shallow water table underlying the site. Subsurface soil and dissolved groundwater contaminants are also present in varying concentrations. In light of regulatory concern and environmental investigation results, interim free-product removal actions are being recommended at this time.

SYNOPSIS OF ENVIRONMENTAL INVESTIGATIONS TO DATE

CONTAMINATED MEDIA OF CONCERN

Several environmental investigations have been conducted at Site 2, including a site investigation performed by ERM-West (ERM-West 1988), NDEP's investigation of an alleged fuel release in January/February 1988 (NDEP 1990), and the IR Program Phase II site characterization performed by Oak Ridge National Laboratory/Grand Junction (ORNL/GJ). Details from the ERM-West and NDEP investigations may be found in the above referenced documents. A synopsis of the ORNL/GJ work follows.

Summary of Previous Investigations

ERM-West

A soil-gas survey was conducted during the ERM-West investigation of the facility. Soil-gas samples were taken at a depth of approximately 0.8 m (2.75 ft) from 85 sample locations. Soil-gas samples were analyzed with a Foxboro Century 128 Organic Vapor Analyzer (OVA) configured for survey mode (ERM-West 1988). Organic vapor concentrations in parts per million (ppm) were determined in unknown samples and related to a known methane concentration to which the instrument had been calibrated. Three areas exhibited high OVA readings as shown in Fig. 3. The three areas include: 1) the oil/water separator leach field area, 2) the area north of the truck refueling pumps, and 3) the area east of Building 201. Although intended to estimate the concentration gradient resulting from underlying contaminants, soil-gas results were sporadic and produced high- and low-concentration readings between adjacent sample locations. Soil-gas analysis in the top 0.8 m (2.75 ft) of surface soil could not accurately determine the underlying plume boundaries due to geological heterogeneities.

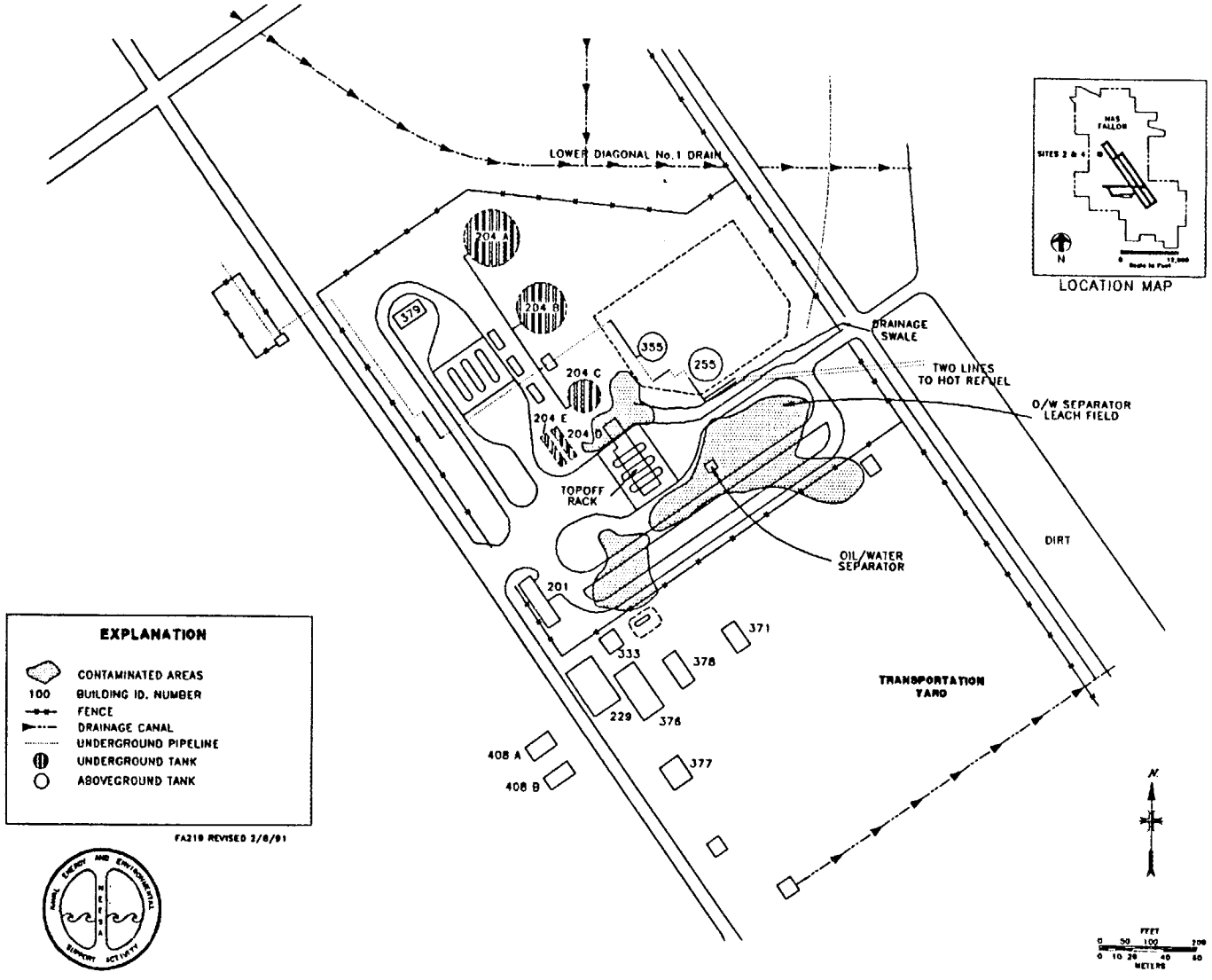


Fig. 3. 1988 ERM–West soil–gas survey showing contaminated areas. Group I Sites: Site 2, New Fuel Farm, and 4, Transportation Yard.

During the week of April 25, 1988, ERM-West completed seven soil borings and installed eight 5-cm-(2-in.) diameter monitoring wells at Site 2 (Fig. 4). Boreholes 23 and 14 were drilled to a depth of 12 m (40 ft) to assess the underlying soils. The remaining five soil borings and eight monitoring wells were advanced to shallower depths to assess contamination in the uppermost permeable zone and to avoid penetration of the impermeable clay layer which underlies the upper permeable zone.

Thirteen soil samples from soil borings and monitoring well boreholes were submitted for laboratory analysis of total petroleum hydrocarbons (TPH) and volatile organic compounds (VOC) (ERM-West 1988). Soil samples were obtained using a California modified sampler fitted with brass sleeves and pushed ahead of the hollow-stem augers during drilling. Samples were collected at intervals of 0.45 m (1.5 ft) to 0.6 m (2.0 ft) in the upper 1.5 m (5 ft) of the boring and at 1.5-m intervals thereafter.

Water samples from the eight monitoring wells were also submitted to the laboratory. Wells were developed by pumping approximately 230 L (60 gal) of water from each well until a clear discharge was established. Five well volumes of water were then removed and temperature, conductivity, and pH checked for stabilization before samples were collected. Sample pumping rates were controlled to minimize degasing of volatiles during sample collection. Laboratory analyses were performed by a California state-certified laboratory, Central Analytical Services, San Luis Obispo, California (ERM-West 1988).

Groundwater sampling results appear in Table 1 and indicate benzene contamination in wells W-15 and W-20 of 0.028 and 0.29 mg/L respectively. In addition, monitoring well W-20 contained 140 cm (4.61 ft.) of floating product. While initial sampling of W-27 indicated TPH contamination at 520 mg/L, results from subsequent sampling efforts indicate no contamination is present. Results from soil sampling (Table 2) indicate elevated TPH concentrations at sample locations W-17, W-20, B-19, B-21, and B-26.

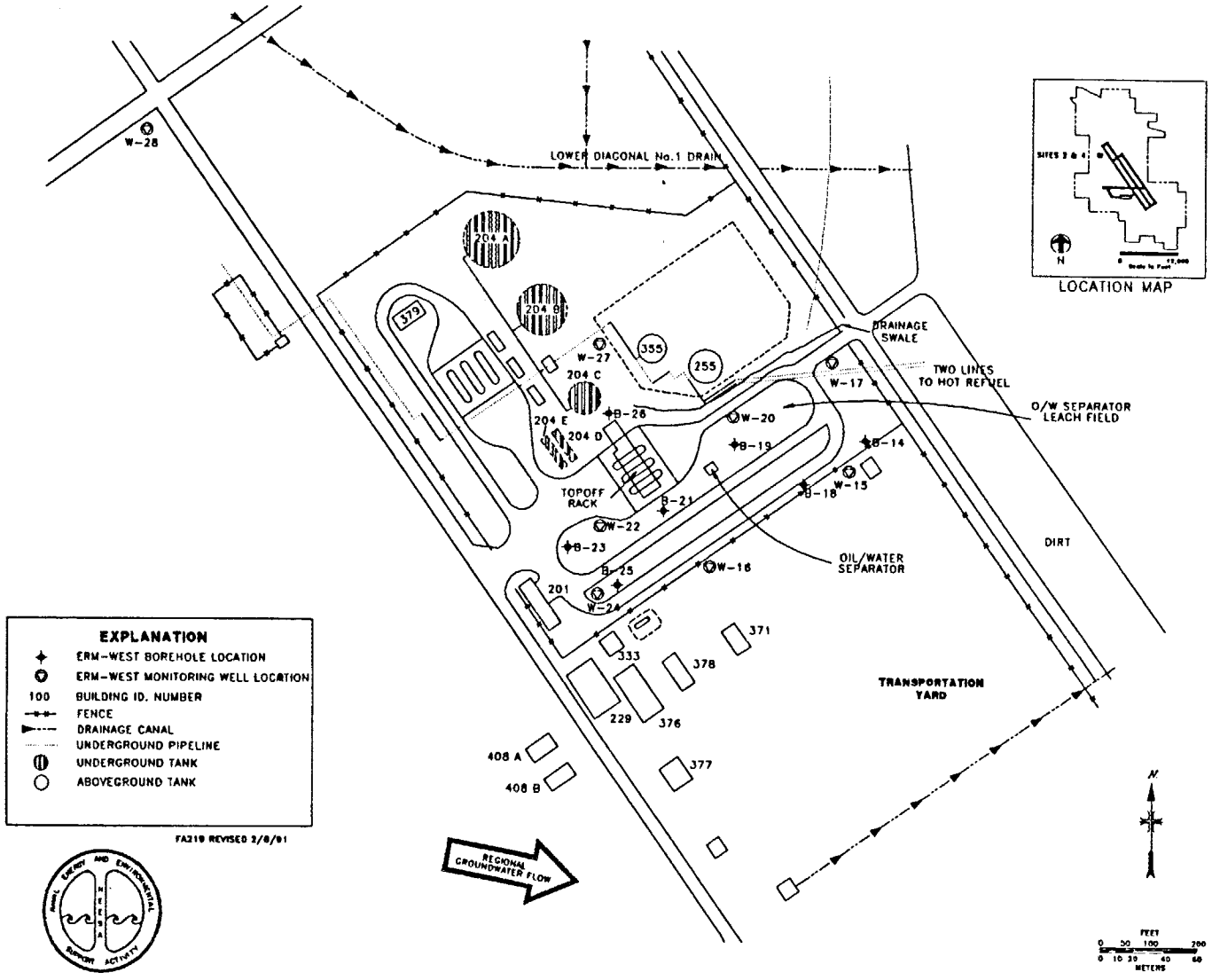


Fig. 4. Location map, ERM-West boreholes and monitoring wells. Group I Sites: Site 2, New Fuel Farm, and Site 4, Transportation Yard.

Table 1. Groundwater analysis, ERM-West investigation

GROUNDWATER ANALYSIS (mg/L)					
Well Number	Analysis				
	Total Petroleum Hydrocarbons Method 418.1, detection limit 0.002	Volatile Organic Compounds Method 601/602, detection limit 0.002			
		Benzene	Ethylbenzene	Toluene	Xylene
W-15	4	0.028	0.011	0.0065	0.16
W-28	<3	0.0013	0.0024	0.0038	0.0049
W-17	<3	0.0007	0.0017	0.0042	0.014
W-16	<3	0.0008	0.0043	0.01	0.03
W-24	<3	0.0018	0.0032	0.008	0.02
W-20	24,000	0.29	0.15	0.008	0.83
W-22	<3	0.0011	0.0014	0.0029	0.0088
W-27	520	0.0012	0.0026	0.0055	0.018

Source: ERM-West 1988; results based on analysis of one round of sampling.

Table 2. Soil analysis, ERM-West investigation

SOIL ANALYSIS (mg/kg)									
		Analysis							
		Total Petroleum Hydrocarbons			Volatile Organic Compounds				
					Method 8010/8020, detection limit 0.01				
Sample Location	Sample Depth in meters	Method 418.1, detection limit 30.0	Method 625/8270, Select Ion, detection limit 1.0	Method 625/8270, Full Scan, detection limit 1.0	Benzene	Ethyl-benzene	Tetra-chloro-ethylene	Toluene	Xylene
W-16	3.6-3.8	ND	NA	NA	NA	NA	NA	NA	NA
W-16	3.8-4.0	ND	NA	NA	NA	NA	NA	NA	NA
W-17	(Comp.)	1,200	ND	ND	NA	NA	NA	NA	NA
B-18	2.9-3.1	ND	NA	NA	NA	NA	NA	NA	NA
B-19	2.1-2.3	ND	NA	2,900	0.15	NA	0.02	0.05	0.90
W-20	3.0-3.2	440	NA	NA	NA	NA	NA	NA	NA
B-21	2.1-2.3	NA	1,100	NA	0.04	0.28	0.01	0.45	1.90
W-22	(Comp.)	ND	NA	NA	0.01	0.01	0.01	0.01	0.01
W-24	(Comp.)	ND	NA	NA	NA	NA	NA	NA	NA
B-26	2.1-2.3	NA	2,300	NA	ND	0.07	ND	0.06	0.44
B-25	(Comp.)	ND	NA	NA	NA	NA	NA	NA	NA
W-27	(Comp.)	ND	NA	NA	NA	NA	NA	NA	NA
W-28	(Comp.)	ND	NA	NA	NA	NA	NA	NA	NA

ND: not detected
NA: not analyzed
Comp: composite
Source: ERM-West 1988; results based on analysis of one round of sampling.

NDEP

Additional analytical information is available from the NDEP investigation of an alleged fuel release in January/February 1988 (NDEP 1990). Soil samples were obtained from ten soil pits and two surface locations (Fig. 5). The soil pits were excavated with a backhoe to a depth of approximately 2.4 m (8 ft) or to groundwater, whichever was shallower. Soil samples were logged at 0.6-m (2-ft) intervals, after being screened with a Photovac photoionization detector (PID) equipped with a 10.6-eV lamp. Samples exhibiting elevated PID readings or suspected of containing contamination were submitted for laboratory analysis to Alpha Analytical, Sparks, Nevada, within 24 hours after collection. Soil samples for laboratory analysis were placed in clean, one-quart jars with a wooden sampling tool and fitted with aluminum lid sleeves. Surface-soil samples collected near the vent systems for underground tanks 204A and 204B and sediment samples collected from the Lower Diagonal No. 1 Drain were also submitted for analysis. Two sediment samples were obtained from the ditch, one at a site upstream from the facility and one immediately downstream from Site 2.

Groundwater samples were also submitted to Alpha Analytical. The groundwater samples included: 1) one sample taken from soil pit number 1, and 2) two samples from domestic drinking-water wells allegedly impacted by activities at NAS Fallon. The drinking-water samples were obtained from two shallow [9 to 15 m (30 to 50 ft)] residential wells located at 2360 Wildes Road and 4225 South Harmon Road. Water samples were collected in clean, one-gallon amber bottles and sealed with teflon-lined caps.

Laboratory results for the NDEP investigation appear in Table 3. The soil samples indicated contamination in three of the soil pits and in the two surface samples. TPH contamination levels of 310, 928, and 12,900 mg/kg were detected in soil pits 7, 9, and 10 respectively. None of the remaining soil pits showed contamination at the detection limit

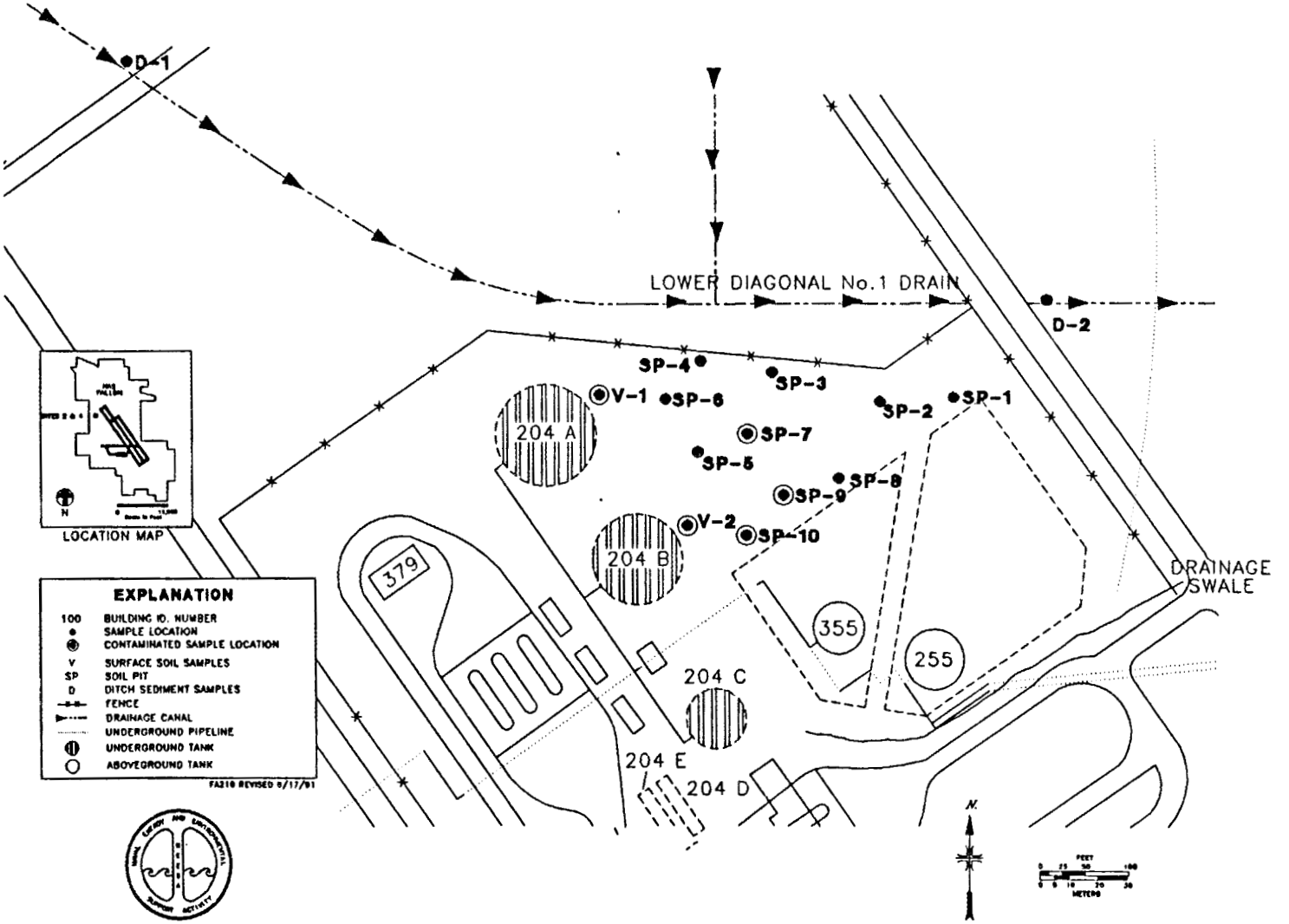


Fig. 5. Nevada Division of Environmental Protection, 1990 sample location map. Group I Site: Site 2, New Fuel Farm. Sample locations approximate. Source: NDEP 1990.

Table 3. Soil and groundwater analysis, NDEP investigation

SOIL AND GROUNDWATER ANALYSIS mg/kg for soil, mg/L for groundwater			
Sample Locations	Sample Media	Total Petroleum Hydrocarbons	
		Soil Method 8015, detection limit 10	Groundwater Method 8015, detection limit 0.5
SP-1	Subsoil	ND	
SP-2	Subsoil	ND	
SP-3	Subsoil	ND	
SP-4	Subsoil	ND	
SP-5	Subsoil	ND	
SP-6	Subsoil	ND	
SP-7	Subsoil	310	
SP-8	Subsoil	ND	
SP-9	Subsoil	928	
SP-10	Subsoil	12,900	
V-1 (tank 204A)	Surface soil	7,690	
V-2 (tank 204B)	Surface soil	2,350	
D-1	Sediment	ND	
D-2	Sediment	ND	
SP-1	Groundwater		ND
Wildes Road	Residential well		ND
South Harmon Road	Residential well		ND

ND: not detected
Source: NDEP 1990; results based on analysis of one round of sampling.

of 10 mg/kg. Surface-soil samples taken near the tank vents indicated petroleum hydrocarbon contamination levels of 7,690 mg/kg near tank 204A and 2,350 mg/kg near tank 204B. These results indicate either discharge from the underground tanks through the vent system or vapor-phase product condensation around the vents. The hydrocarbon compounds encountered in the samples were consistent with those found in JP-5 and diesel. As shown in Table 3, none of the groundwater, domestic wells, or sediment samples contained petroleum hydrocarbons above the method detection limit (NDEP 1990).

Summary of IR Program-Phase II Preliminary Site Characterization

At the completion of Phase I of the IR Program at NAS Fallon, the Naval Energy and Environmental Support Activity (NEESA) recommended that 21 sites, including Site 2, the New Fuel Farm, be carried over into Phase II (Dames and Moore 1988). For simplicity in referencing, similar sites were grouped together; Site 2, the New Fuel Farm, was combined with Site 4, the Transportation Yard, for collective reference as Group I Sites. In an effort to maintain consistency, figures and location maps in this document refer to Site 2 as part of the Group I Sites. ORNL/GJ began Phase II site characterization in September 1989 by implementing a geophysical survey, a soil-gas survey, and a field screening of ninety shallow boreholes. Field screening results were used to locate installation points for fifteen groundwater monitoring wells. Laboratory analysis of groundwater samples and soil samples taken from the monitoring wells has provided insight concerning the magnitude and extent of contamination underlying the facility.

The geophysical and soil-gas surveys were conducted in August and September of 1989. Soil-gas samples were taken at a depth of approximately 1.65 m (5.5 ft) in hopes that the additional depth of sample (as compared to the 0.8 m depth used in the ERM-West investigation) would

increase the chances of detecting volatile contaminants in the underlying water table. A Photovac 10S50 gas chromatograph (GC) was used to screen soil-gas samples. In general, soil-gas samples were taken on grid points which proceeded outward from areas of known contamination to areas where sample results were at the detection limits of the GC. Like the ERM-West survey, results from the soil-gas survey were inconclusive in that the contaminant plume was not continuous but appeared to contain sporadic areas where no contaminated soil-gas was detectable. These findings may result from varying hydrogeologic conditions and relatively impermeable clay lenses which impede the flow of vapor-phase contaminants from the groundwater into the unsaturated zone. Soil-gas results were thus viewed in a qualitative sense only. The Phase II investigation confirmed potential source areas of jet-fuel contamination identified in the ERM-West report including: 1) the faulty oil/water separator, 2) runoff spills from the asphalt parking area, and 3) the tank-bottom-sludge disposal area east of underground tank 204C (Fig. 6).

The geophysical survey employed a Geonics EM-31 electro-magnetometer (EM) coupled with an ultrasonic ranging and data collection system (USRADS). The EM survey mapped differences in the electrical conductivity of underlying soil believed to be associated with floating jet fuel and fresh-water recharge. Potential sources of fresh-water recharge and/or contamination were identified as the oil/water separator leach field, a leaky water hydrant near the fuel truck top-off rack, and ponding runoff from rainfall (Fig. 7).

During May, June, and July 1990, a light utility drilling rig drilled ninety 7.5-cm-(3-in.-)diameter boreholes in and around Site 2. The holes ranged in depth from 4 to 6 m (13 to 20 ft) with most being 4.5 m (15 ft) deep. The boreholes provided access to the underlying aquifer, and groundwater samples were taken and analyzed for volatile contaminants. The sampling method consisted of first monitoring the open borehole with an HNU-101 PID and then collecting a groundwater sample in a 4.5-cm- (1.75-in.)diameter teflon bailer. Upon removal from the borehole, the sample was visually inspected for the presence of

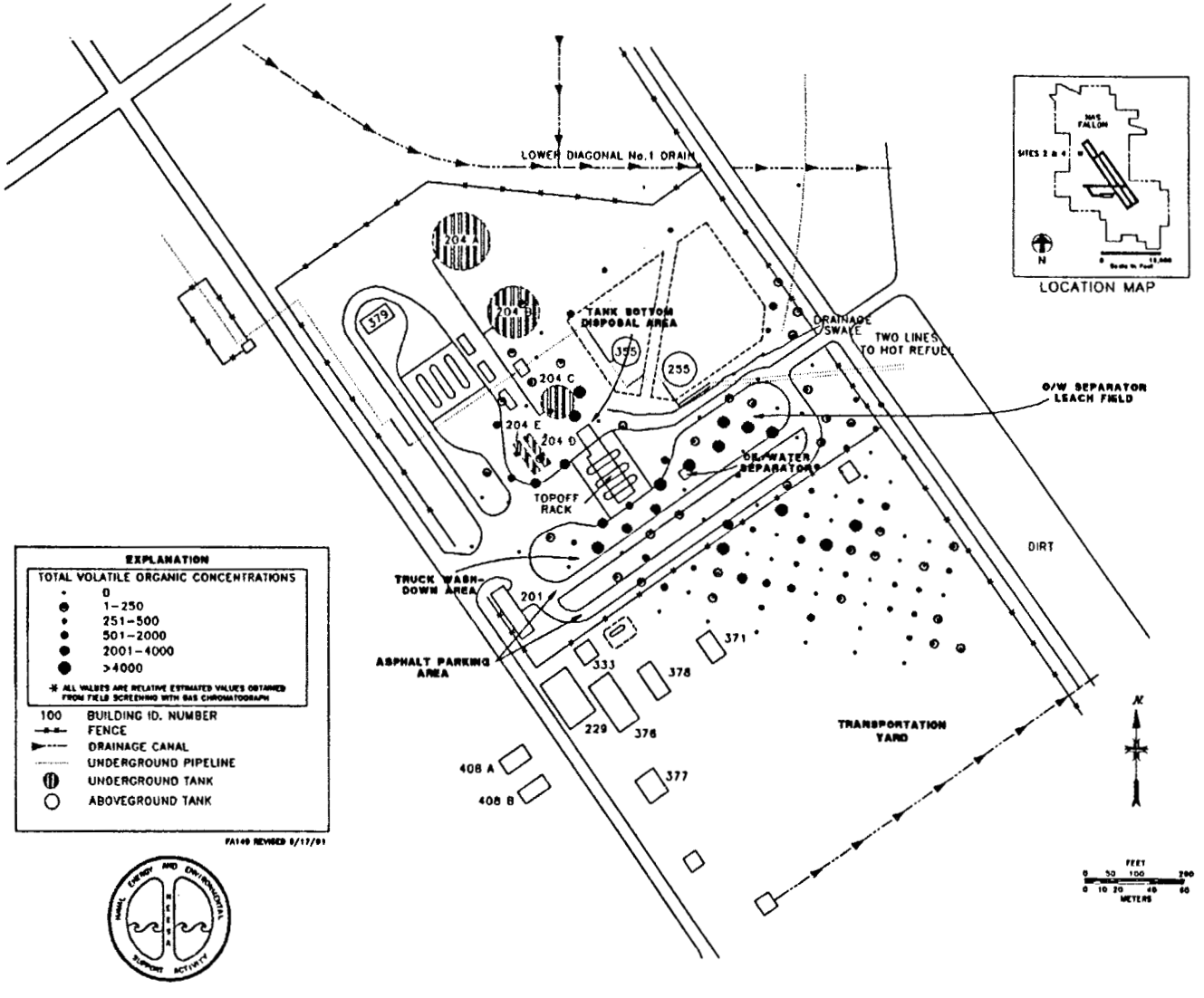


Fig. 6. Soil-gas total volatile organic concentrations. Group I Sites: Site 2, New Fuel Farm, and Site 4, Transportation Yard. ORNL, 1989.

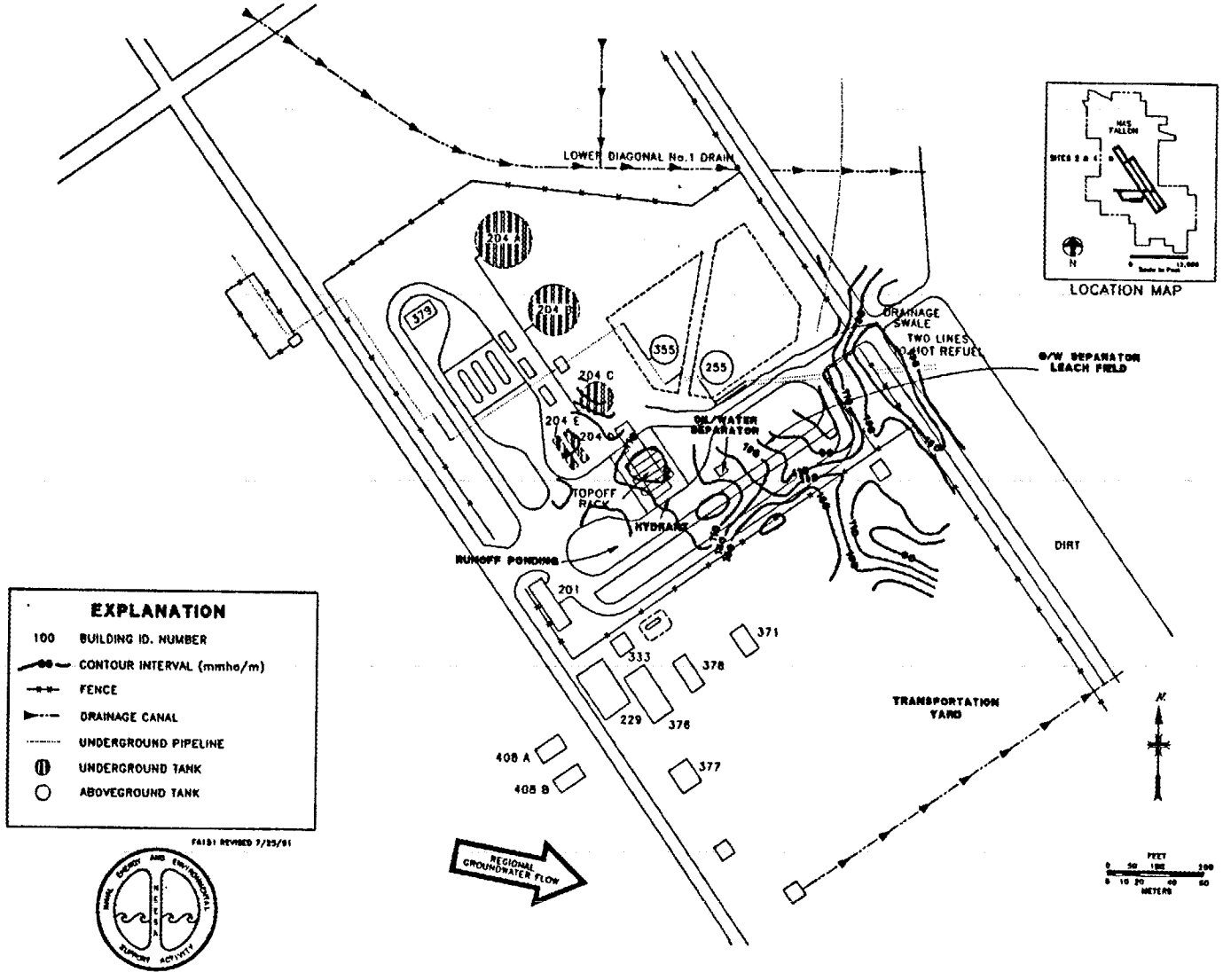


Fig. 7. In-phase geophysical contour map. Group I Sites: Site 2, New Fuel Farm, and Site 4, Transportation Yard. ORNL, 1989.

free product. If relatively high PID readings (greater than 50 ppm) or visible free product were encountered, the sample was not subjected to further analysis, and the borehole was labeled contaminated. For those boreholes not exhibiting obvious groundwater contamination, the groundwater sample was transferred to 125-ml-septum vials with approximately 30 ml of headspace left in the top of each vial. Samples were agitated and allowed to stand for approximately 15 minutes to allow volatile components to reach equilibrium in the headspace. Finally, a 100 μL headspace sample was analyzed for VOCs with a field-portable GC. Sample locations for groundwater screening were determined by moving outward on 50-ft grid points from areas of known contamination until no contamination was detected with the field GC.

As a test of the sampling procedure, ten water samples were sent to Chemax Laboratory in Reno for overnight analysis of VOCs. The lab results confirmed the recorded field classifications of "clean" or "contaminated" (as determined by either visual inspection, PID, or field GC) for all samples tested.

The borehole screening provided a consistent method for detecting free product in a large number of floating-product/groundwater samples. Up to several inches of floating product were observed on bailed samples taken during the program, and these results provide the most accurate delineation to date of the spatial extent of free product underlying Site 2. However, these observations may not accurately indicate the amount or thickness of actual free product underlying the site. Because bailed samples were taken shortly after each borehole was completed, recharge to steady-state conditions cannot be assumed, and additional free product may have flowed into the borehole if fluid levels had been allowed to stabilize. Borehole screening results should thus be viewed as confirming the presence of <u>at least</u> several inches of floating product. These results establish the approximate boundary of petroleum hydrocarbon contaminants underlying Site 2.

The borehole screening program greatly expanded the area of known contamination. In addition to the contaminants associated with the oil/water separator, three additional areas of contamination were identified as: 1) the area east of underground tank 204A, 2) the area between the pumping station and the fuel farm, and 3) the area near a former sump used for collecting fuel from leaking tanker trucks at the fuel farm. Sample locations and areas where free product is evident are shown in Fig. 8.

Phase II site characterization work also included installing fifteen 5-cm-(2-in.-)diameter monitoring wells and one pumping well in and around Site 2. Monitoring well MW06 U&L was installed as a dual-completion, "clean", upgradient well. Wells MW07 (single completion), MW08 U&L (dual completion), and MW09 (single completion) were installed between the fuel facility and the Lower Diagonal No. 1 Drain. After purging, the upper completion of MW08 failed to recharge, and MW08 was replaced with MW13. The remaining eight wells were installed down-gradient along the southern and eastern site boundaries. MW03 U&L and MW05 U&L are dual completions and the other four wells are single completions. A 13-cm- (5-in.-)diameter pumping well, PW01, was installed as an offset to MW04. The pumping well was used to determine hydrologic parameters of the underlying aquifer.

Well placement resulted in collecting soil samples and two rounds of groundwater samples. Soil samples were taken continuously with a split spoon or a California sampler during well installation. Sampling methods are described in the Phase II RI/FS Work Plan (ORNL/GJ 1989). In addition, several surface-soil samples, as well as surface-water and sediment samples from the Lower Diagonal No.1 Drain, were collected. Soil samples from the monitoring wells were logged for soil type and lithology and screened with the field GC. Samples suspected of containing contaminants were submitted for laboratory analysis.

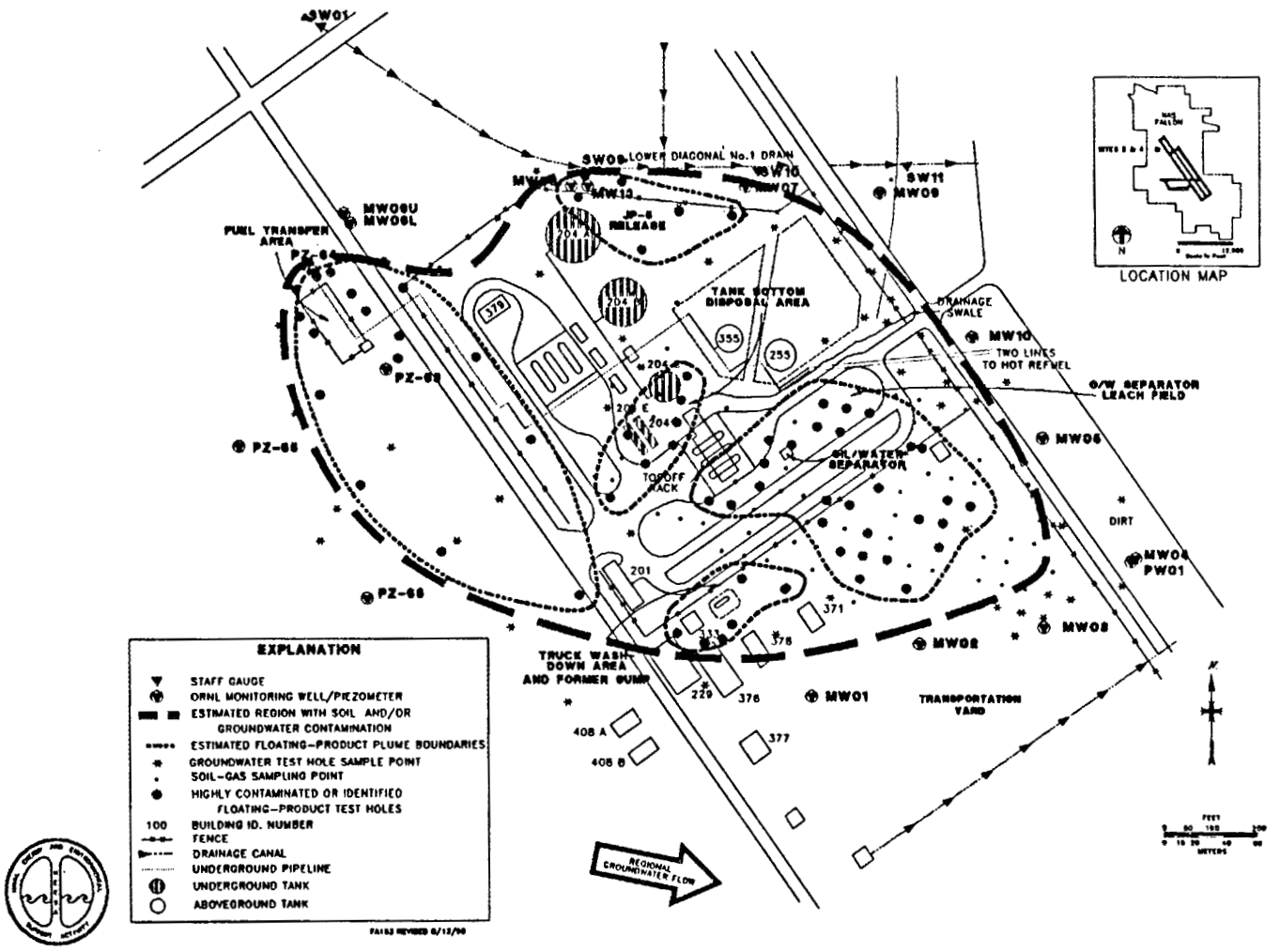


Fig. 8. Map showing groundwater testholes, contamination source areas, ORNL monitoring wells, and floating-product plumes. Group 1 Sites: Site 2, New Fuel Farm, and Site 4, Transportation Yard. Boundaries shown are estimates from field screening.

Groundwater sampling and analysis were performed after well development. Four of the existing ERM-West wells were also sampled. This initial round of groundwater sampling was completed in July 1990. Samples were submitted for laboratory analysis using method 418.1 for petroleum hydrocarbons as well as other methods specified in the work plan. A second round of groundwater samples was taken in November 1990. Laboratory analysis of the second batch of samples employed the California modified 8015 method for detection of total petroleum hydrocarbons as well as analysis for VOCs and metals.

The locations of wells, surface-water samples, sediment samples, and surface-soil samples appear in Fig. 9. Analysis of surface-water samples taken at SW1 on September 27, 1989, and October 10, 1989, indicate TPH values of 5.0 mg/L and 2.0 mg/L respectively. Surface-water analysis of a sample taken at SW2 on October 11, 1989 revealed a TPH value of 5.0 mg/L. Groundwater- and soil-sampling results are given in Tables 4, 5, and 6.

The groundwater metals and anion analyses indicate saline conditions with the presence of arsenic, selenium, sodium, boron, lead, vanadium, mercury, lithium, magnesium, and calcium. Values for arsenic (up to 4 mg/L) exceed drinking water standards of 0.050 mg/L. Naturally occurring arsenic concentrations of 0.026 mg/L (Lico, Welch, and Hughes 1987) and 0.061 to 0.730 mg/L (Hoffman et al. 1987) have been reported regionally in the surrounding shallow groundwater. Most of the groundwater which is not near a point of fresh water recharge is brackish and contains abundant dissolved salts.

Naturally high total-dissolved-solids (TDS) occurring in the upper aquifer of the region has rendered the groundwater in parts of the Carson Desert unfit for domestic use (Glancy 1986). Because activities conducted at Site 2 have limited (if any) potential to introduce the metals and anions listed above into the environment, their presence is not attributable to NAS Fallon activities.

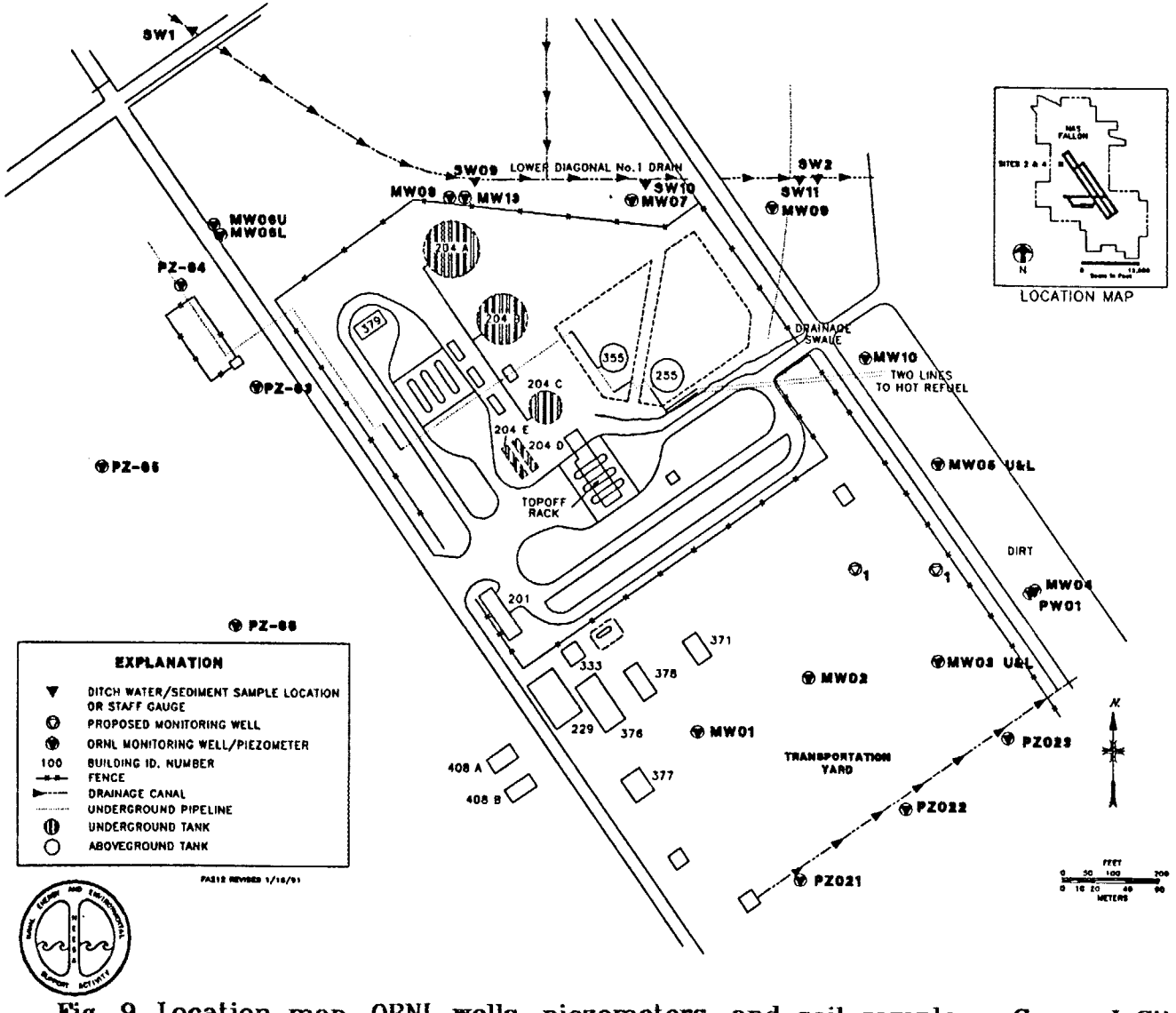


Fig. 9. Location map, ORNL wells, piezometers, and soil samples. Group I Sites: Site 2, New Fuel Farm, and Site 4, Transportation yard.

Table 4. Site 2 anion and metal analysis, groundwater - ORNL/GJ investigation

Anions, mg/L Method 429 Quantitation limit: 0.5 mg/L				
Compound	Times found	Average	Minimum	Maximum
Chloride	20	916.30	7.20	2400.00
Fluoride	4	1.90	0.61	3.60
Nitrate, as N	5	11.10	4.60	18.00
Phosphate	0			
Sulfate	20	1513.60	2.60	3900.00
Metals, μg/L Quantitation limit: 1 μg/L				
Aluminum	13	181.20	41.70	1460.00
Antimony	1	38.20	38.20	38.20
Arsenic	37	1290.00	15.30	4660.00
Barium	37	57.90	13.60	139.00
Beryllium	2	1.30	1.20	1.40
Boron	43	30,322.30	1050.00	91,700.00
Cadmium	0			
Calcium	22	43,147.30	1880.00	205,000.00
Chromium	0			
Cobalt	0			
Copper	18	31.20	10.60	77.20
Iron	20	141.90	26.00	1420.00
Lead	9	3.20	2.00	5.50
Lithium	43	81.20	27.90	153.00
Magnesium	22	17,254.10	971.00	59,300.00
Manganese	20	374.10	2.20	2050.00
Mercury	1	0.21	0.21	0.21
Molybdenum	19	430.00	30.10	1310.00
Nickel	0			
Potassium	22	37,316.80	5630.00	130,000.00
Selenium	3	26.00	21.50	30.70
Silver	5	6.70	5.00	9.00
Sodium	25	2,552,800.00	131,000.00	8,790,000.00
Thallium	0			
Vanadium	30	277.40	16.70	1230.00
Zinc	28	56.50	7.30	338.00

Table 5. Site 2 water analysis - ORNL/GJ investigation

Location	Sample number	Date	Total HBP PHC (*1) ug/L	Total LBP PHC (*2) ug/L	Total PHC Method 418.1 mg/L QL: 1 mg/L	Semivolatiles Method 625, ug/L QL: 10 ug/L		Volatiles Method 624, ug/L QL: 5 ug/L	
EW016	3473	07/15/90	#	#	U	Bis2	120.0	U	
EW016	3516	10/31/90	U	U	#	#		Methcl	1.0
EW017	3471	07/15/90	#	#	U	TIC 1	11.0	Acet	2.0
						TIC 2	15.0		
						TIC 3	16.0		
						2 unknowns	8.2		
							12.0		
EW017	3517	10/31/90	U	U	#	#		U	
EW022	3474	07/15/90	#	#	U	Bis2	36.0	Methcl	3.0
						TIC 6	8.0		
						1 unknowns	24.0		
							24.0		
EW022	3475	07/15/90	#	#	U	Bis2	30.0	Methcl	1.0
						TIC 5	14.0		
						1 unknowns	48.0		
							48.0		
EW022	3515	10/30/90	U	U	#	#		Carbdi	1.0
EW027	3476	07/15/90	#	#	U	Bis2	39.0	Acet	1.0
						TIC 5	17.0	Methcl	1.0
EW027	3477	07/15/90	#	#	U	Bis2	19.0	Methcl	1.0
						TIC 5	33.0		
EW027	3533	11/02/90	U	U	#	#		U	
MW001	3463	07/13/90	#	#	U	TIC 1	16.0	Acet	2.0
						TIC 9	73.0		
						TIC 3	140.0		
						2 unknowns	10.0		
							11.0		
MW001	3532	11/02/90	U	U	#	#		U	
MW002	3464	07/13/90	#	#	U	TIC 1	11.0	Acet	4.0
						TIC 9	42.0		
						TIC 3	27.0		
						1 unknowns	14.0		
							14.0		
MW002	3526	11/01/90	U	U	#	#		Methcl	1.0
MW003L	3466	07/13/90	#	#	U	1 unknowns	15.0	U	
							15.0		
MW003L	3530	11/02/90	U	140.0	#	#		U	
MW003U	3470	07/14/90	#	#	U	1 unknowns	24.0	U	
							24.0		

Table 5. (continued)

Location	Sample number	Date	Total HBP PHC (*1) ug/L	Total LBP PHC (*2) ug/L	Total PHC Method 418.1 mg/L QL: 1 mg/L	Semivolatiles Method 625, ug/L QL: 10 lg/L	Volatiles Method 624, ug/L QL: 5 lg/L
MW003U	3531	11/02/90	U	U	#	#	U
MW003U	3564	11/05/90	U	U	#	#	U
MW004	3454	07/11/90	#	#	U	U	U
MW004	3538	11/03/90	U	U	#	#	U
MW004	3565	11/05/90	U	U	#	#	U
MW005L	3456	07/12/90	#	#	U	U	Acet 1.0
MW005L	3536	11/03/90	U	84.0	#	#	U
				T 1.0			
				X 6.0			
MW005U	3459	07/12/90	#	#	U	Bis2 2.0	U
						TIC 10 20.0	
						TIC 11 12.0	
MW005U	3537	11/03/90	U	U	#	#	Methcl 3.0
MW006L	3461	07/13/90	#	#	U	Bis2 19.0	U
						TIC 12 71.0	
						1 unknowns 13.0	
						13.0	
MW006L	3544	11/04/90	U	U	#	#	Methcl 4.0
MW006U	3465	07/13/90	#	#	U	TIC 3 14.0	U
						TIC 13 9.5	
						2 unknowns 8.6	
						86.0	
MW006U	3542	11/04/90	U	U	#	#	Methcl 2.0
MW006U	3543	11/04/90	U	U	#	#	Methcl 4.0
MW007	3478	07/15/90	#	#	U	Bis2 70.0	U
						3 unknowns 8.0	
						9.3	
MW007	3507	07/26/90	#	#	3	#	#
MW007	3523	11/01/90	U	U	#	#	U
MW007	3524	11/01/90	U	U	#	#	U
MW008L	3480	07/16/90	#	#	U	TIC 14 12.0	U
						TIC 15 36.0	
						TIC 16 26.0	
						TIC 17 170.0	
						1 unknowns 16.0	
						16.0	

Table 5. (continued)

Location	Sample number	Date	Total HBP PHC (*1) ug/L	Total LBP PHC (*2) ug/L	Total PHC Method 418.1 mg/L QL: 1 mg/L	Semivolatiles Method 625, ug/L QL: 10 lg/L		Volatiles Method 624, ug/L QL: 5 lg/L	
MW008L	3480R	07/16/90	#	#	#	TIC 18	10.0	#	
						TIC 14	12.0		
						TIC 15	30.0		
						TIC 16	14.0		
						TIC 17	140.0		
						2 unknowns	12.0		
							28.0		
MW008L	3521	11/01/90	U	U	#	#		U	
MW009	3460	07/12/90	#	#	U	TIC 19	12.0	Acet	4.0
MW009	3535	11/02/90	U	U	#	#		U	
MW010	3457	07/12/90	#	#	2	Bis2	63.0	U	
MW010	3541	11/04/90	U	U	#	#		Methcl	2.0
MW013	3508	07/26/90	#	#	U	TIC 3	8.9	TIC 20	5.2
						1 unknowns	9.1	TIC 21	9.6
							9.1	TIC 22	13.0
								TIC 23	17.0
								TIC 24	8.1
								TIC 25	20.0
								TIC 26	7.5
								3 unknowns	5.3
									15.0
MW013	3522	11/01/90	U	110.0	#	#		E	3.0
				B 0.9				X	2.0
								TIC 21	5.6
								TIC 22	4.4
								TIC 27	5.2

- not analyzed
*1 - Method 8015 Modified, quantitation limit: 50 ug/L
*2 - Method 8015/8020, quantitation limit: 50 ug/L
Acet - acetone
B - benzene, QL = 0.5 ug/L
Bis2 - bis(2-Ethylhexyl) phthalate
Bro - bromoform
Carbdi - carbon disulfide
Dibro - dibromochloromethane
E - ethylbenzene
HBP - high boiling point
LBP - low boiling point
Methcl - methylene chloride
PHC - petroleum hydrocarbons
QL - quantitation Limit
T - toluene, QL = 1 ug/L
TIC - tentatively identified compound
U - no compounds detected
X - xylenes (total), QL = 4 ug/L

TIC 1 - 2-hexenal
TIC 2 - butane, 1-(2-methoxyethoxy)-
TIC 3 - cyclohexanol, 2-bromo-
TIC 4 - 1,2-benzenedicarboxylic acid
TIC 5 - 2-pentanone, 4-hydroxy-4-met
TIC 6 - hexadecanoic acid
TIC 7 - 1,3-cyclopentanedione
TIC 8 - cyclohexanol, 2-cloro-
TIC 9 - cyclohexanol, 1-bromo-2-chlor
TIC 10 - 2-pentanone rt=3.43
TIC 11 - caprolactam rt=11.12
TIC 12 - sulfur, mol. (s8)
TIC 13 - ethanol, 2-(2-butoxyethoxy)-
TIC 14 - 7-oxabicyclo
TIC 15 - cyclohexane
TIC 16 - ethanol
TIC 17 - furan
TIC 18 - 2-pentanone
TIC 19 - 2-pentanone rt=3.42
TIC 20 - benzene, 1,2,4-trimethyl-
TIC 21 - benzene, 1-ethyl-2-methyl-
TIC 22 - cyclohexane (dot)
TIC 23 - cyclohexane, methyl-
TIC 24 - cyclopentane, 1,2-dimethyl-
TIC 25 - cyclopentane, 1-(ethenloxy)-2-
TIC 26 - propane
TIC 27 - cyclopentane, methyl-

Table 6. Site 2 soil analysis - ORNL/GJ investigation

Location	Sample number	Exact location	Date	Total PHC Method 418.1 mg/kg QL: 1 mg/kg	Semivolatiles Method 3550/8270, µg/kg QL: 350 µg/kg		Volatiles Method 8240, µg/kg QL: 5 µg/kg	
MW002	3436	6.5'- 7'	06/17/90	U	Bis2	430.0	Acet	10.0
					TIC 1	630.0	Methcl	8.0
					TIC 2	33,000.0		
					TIC 3	4300.0		
					TIC 4	170.0		
					1 unknowns	580.0		
						580.0		
MW004	3439	8.5' - 9'	06/18/90	U	Bis2	1600.0	Acet	6.0
					TIC 5	940.0	Methcl	4.0
					TIC 6	46,000.0	T	1.0
					TIC 7	5400.0		
					TIC 8	200.0		
					TIC 9	160.0		
					TIC 10	450.0		
					TIC 11	370.0		
					5 unknowns	160.0		
						200.0		
MW005	3443	6.5' - 7'	06/19/90	U	Bis2	3900.0	Acet	8.0
					TIC 5	820.0	Methcl	6.0
					TIC 12	36,000.0	T	4.0
					TIC 7	4500.0		
					TIC 9	370.0		
					TIC 11	250.0		
					3 unknowns	200.0		
						660.0		
MW005	3444	8.5' - 9'	06/19/90	U	Bis2	800.0	Methcl	5.0
					TIC 12	40,000.0	T	3.0
					TIC 13	180.0		
					TIC 14	4800.0		
					TIC 15	350.0		
					1 unknowns	220.0		
						220.0		
MW006	3447	6.5' - 7'	06/20/90	13	Bis2	190.0	Methcl	15.0
					TIC 5	370.0	TIC 19	3.5
					TIC 16	290.0		
					TIC 17	33,000.0		
					TIC 18	3900.0		
					TIC 10	290.0		

Table 6. (continued)

Location	Sample number	Exact location	Date	Total PHC Method 418.1 mg/kg QL: 1 mg/kg	Semivolatiles Method 3550/8270, µg/kg QL: 350 µg/kg		Volatiles Method 8240, µg/kg QL: 5 µg/kg	
MW008	3450	6.5' - 7'	06/23/90	16	Bis2	2100.0	Acet	2.0
					TIC 20	290.0	Methcl	32.0
					TIC 21	250.0	TIC 19	4.7
					TIC 22	40,000.0		
					TIC 18	4500.0		
					TIC 9	210.0		
					TIC 10	380.0		
					1 unknowns	290.0		
						290.0		
MW009	3451	6.5' - 7'	06/23/90	U	Bis2	1100.0	Acet	1.0
					TIC 5	630.0	Methcl	19.0
					TIC 6	36,000.0	TIC 19	4.5
					TIC 18	4000.0		
					TIC 7	160.0		
					TIC 10	280.0		
					1 unknowns	240.0		
						240.0		
SD001	3154	STAFF GAUG	08/25/89	7	Bis2	1200.0	Acet	31.0
					TIC 23	1800.0	Methcl	10.0
					TIC 6	68,000.0		
					TIC 24	5700.0		
					TIC 25	2400.0		
					5 unknowns	640.0		
						3600.0		
SD002	3158	40' W of C	08/25/89	11	Bis2	2800.0	Acet	57.0
					TIC 23	2600.0	Methcl	14.0
					TIC 6	120,000.0	1 unknowns	21.0
					TIC 24	8300.0		21.0
					TIC 25	4600.0		
					TIC 25	4600.0		
					3 unknowns	1100.0		
						6000.0		
SF001	3175	700E 300N	09/06/89	40	Bis2	300.0	#	
					TIC 23	760.0		
					TIC 6	32,000.0		
					TIC 26	380.0		
					TIC 27	600.0		
					TIC 7	840.0		
					TIC 28	680.0		
					1 unknowns	2700.0		
						2700.0		

Table 6. (continued)

Location	Sample number	Exact location	Date	Total PHC Method 418.1 mg/kg QL: 1 mg/kg	Semivolatiles Method 3550/8270, µg/kg QL: 350 µg/kg		Volatiles Method 8240, µg/kg QL: 5 µg/kg
SF001	3176	700E 300N	09/06/89	15	Bis2	460.0	#
					TIC 29	1600.0	
					TIC 30	24,000.0	
					TIC 31	140.0	
					TIC 7	370.0	
					TIC 28	750.0	
					TIC 32	190.0	
					TIC 33	49.0	
					3 unknowns	170.0	
						2700.0	
SF002	3177	600E 450N	09/06/89	140	Bis2	330.0	#
					TIC 29	1100.0	
					TIC 6	65,000.0	
					1 unknowns	3400.0	
						3400.0	
SF002	3178	600E 450N	09/06/89	2	Bis2	300.0	#
					TIC 34	190.0	
					TIC 29	760.0	
					TIC 6	18,000.0	
					TIC 27	200.0	
					TIC 7	380.0	
					TIC 28	1500.0	
					TIC 32	200.0	
					TIC 33	49.0	
					3 unknowns	260.0	
						1700.0	
SF003	3179	675E 375N	09/06/89	43	Bis2	330.0	#
					TIC 5	680.0	
					TIC 6	34,000.0	
					TIC 27	570.0	
					TIC 7	880.0	
					1 unknowns	2200.0	
						2200.0	
SF003	3180	675E 375N	09/06/89	U	Bis2	290.0	#
					TIC 35	150.0	
					TIC 34	190.0	
					TIC 29	1500.0	
					TIC 6	19,000.0	
					TIC 7	270.0	
					TIC 28	1600.0	
					3 unknowns	280.0	
						2300.0	

Table 6. (continued)

Location	Sample number	Exact location	Date	Total PHC Method 418.1 mg/kg QL: 1 mg/kg	Semivolatiles Method 3550/8270, µg/kg QL: 350 µg/kg		Volatiles Method 8240, µg/kg QL: 5 µg/kg
SF004	3181	600E 200N	09/06/89	4	Bis2	360.0	#
					TIC 5	850.0	
					TIC 29	910.0	
					TIC 6	56,000.0	
					TIC 27	370.0	
					TIC 7	1400.0	
					TIC 28	300.0	
					TIC 11	3200.0	
					1 unknowns	3200.0	
						3200.0	
SF004	3182	600E 200N	09/06/89	U	Bis2	460.0	#
					TIC 29	1200.0	
					TIC 6	21,000.0	
					TIC 7	620.0	
					TIC 36	1000.0	
					TIC 37	180.0	
					TIC 11	350.0	
					TIC 38	690.0	
					TIc 33	58.0	
					3 unknowns	250.0	
						1800.0	
SF004	3183	600E 200N	09/06/89	U	Bis2	380.0	#
					TIC 5	880.0	
					TIC 39	230.0	
					TIC 40	470.0	
					TIC 29	630.0	
					TIC 6	33,000.0	
					TIC 26	500.0	
					TIC 7	1700.0	
					TIC 41	370.0	
					TIC 28	170.0	
					4 unknowns	180.0	
						2600.0	

- not analyzed
Acet - acetone
Bis2 - bis(2-Ethylhexyl) phthalate
Methcl - methylene chloride
PHC - petroleum hydrocarbons
QL - quantitation Limit
T - toluene
TIC - tentatively identified compound
U - no compounds detected

TIC 1 - 1(5h)-furanone rt=6.92
TIC 2 - 2-pentanone rt=4.92
TIC 3 - 3-penten-2-one rt=3.77
TIC 4 - 4-penten-2-one rt=2.70
TIC 5 - 2(5h)-furanone
TIC 6 - 2-pentanone
TIC 7 - 3-penten-2-one
TIC 8 - 3-penten-2-one rt=2.42
TIC 9 - 4-penten-2-one
TIC 10 - formamide
TIC 11 - hexanedioic acid
TIC 12 - 2-pentanone, 4-hydroxy-
TIC 13 - 3-penten-2-one rt-2.43
TIC 14 - 3-penten-2-one rt=3.75
TIC 15 - 4-penten-2-one rt=2.68
TIC 16 - 2-pentanone rt=3.07
TIC 17 - 2-pentanone rt=3.73
TIC 18 - 3-hexen-2-one
TIC 19 - Trichlorofluoromethane
TIC 20 - 2(5h)-furanone rt=5.77
TIC 21 - 2(5h)-furanone rt=5.97
TIC 22 - 2-pentanone rt=3.78
TIC 23 - 2-heptanol
TIC 24 - acetic acid
TIC 25 - hexene-2-one
TIC 26 - 2-propanone
TIC 27 - 3-heptanone
TIC 28 - 5-hexen-2-one
TIC 29 - 2-hexanone
TIC 30 - 2-pentanone (1)
TIC 31 - 2-pentanone (2)
TIC 32 - hexadecanoic acid
TIC 33 - n-nitrosodiphenylamine (1)
TIC 34 - 2,5-hexanedione
TIC 35 - 1-heptanol
TIC 36 - 5-hexen-2-one (1)
TIC 37 - 5-hexen-2-one (2)
TIC 38 - hexanedioic acid, dioctyl es
TIC 39 - 2-butanone
TIC 40 - 2-butenal
TIC 41 - 3-penten-2-one (2)

The ORNL/GJ Phase II assessments combined with results from previous investigations provide a comprehensive data base for characterization of contaminants underlying the New Fuel Farm. Table 7 summarizes the environmental sampling completed at Site 2 and lists the type of sample and party responsible for each sample.

Extent and Degree of Contamination

Laboratory analyses have confirmed areas where contamination exceeds NDEP-established action limits (100 ppm TPH for soil and 5 μg/L dissolved benzene for groundwater). In addition, sampling has confirmed the presence of free product floating on the underlying water table well in excess of the 1.27-cm (0.5-in.) NDEP action limit. While the borehole screening results shown in Fig. 8 indicate the extent of underlying free product, the extent of groundwater and soil contamination remains uncertain. Areas around the site where contamination exceeds established action limits appear to be sporadic, probably the result of past leaks, spills, and accidental discharges occurring over the lifetime of facility operation. Additional environmental testing is necessary to assess the soil and groundwater contamination present at Site 2. An additional round of groundwater sampling was initiated at Site 2 in November 1990.

ENVIRONMENTAL ASSESSMENT

Access to Site 2 is restricted to Naval personnel and subcontractors, thus isolating the general public from the on-site contamination identified. Because most of the on-site contamination lies in the shallow subsurface, exposure is limited to general-construction, maintenance, or remedial activities penetrating the subsurface. Institutional constraints, health and safety awareness, environmentally sound construction practices, and interim corrective measures (protective clothing, monitoring, decontamination) may all be employed to

Table 7. Summary of environmental sampling at Site 2

ENVIRONMENTAL SAMPLING SUMMARY		
Responsible Party	Assessment Method	Number of Sample Locations
ORNL/GJ	Soil-gas	140
	Soil borings	4
	Groundwater test holes	97
	Groundwater wells	15
	Piezometers	4
	Staff gauges	4
	Surface water/sediment	2
ERM-West	Soil-gas	85
	Soil borings	5
	Groundwater wells	8

Note: Multiple samples were often collected at each sample location.

promote on-site environmental protection.

The primary threat posed by contaminants at Site 2 is through off-site transport to potential exposure points. Environmental investigations have found no evidence of off-site transport. Indeed, the 1990 NDEP investigation (NDEP 1990) found no evidence of contaminants migrating from Site 2 to off-site domestic wells or surface flow in the Lower Diagonal No. 1 Drain. Nonetheless, mitigating future contaminant transport is of paramount importance in assuring environmental protection. The following section investigates the principal transport mechanisms and potential exposure points associated with Site 2.

Transport Mechanisms and Migration Pathways

Off-site contaminant transport is facilitated by surface- and/or subsurface-transport mechanisms. Both mechanisms have the potential to transport contaminants in either the free or dissolved state to off-site receptors.

The migration pathway for surface transport consists of flow of a surface release along drainage swales and ditches into off-site surface-water discharge. The principle surface-flow migration pathway for Site 2, the Lower Diagonal No. 1 Drain, has the potential to transport contaminants to the Stillwater National Wildlife Refuge. Berms and surface-flow collection sumps are used at the facility to control surface-water discharge. Such physical containment, combined with routine inspection and sampling, reduce the risk of exposure via off-site surface transport.

Subsurface transport is initiated from percolation of surface discharges or direct flow from leaking underground piping or tanks into the subsurface environment. Migration pathways include natural or man-made preferential flow channels and seeps discharging to surface-water

drainage systems. Environmental exposure may occur if contaminants reach groundwater-supply wells or surface-water exposure points described above.

Alluvium underlying the facility is stratified with heterogeneities created by past meandering stream channels (Morrison 1964). Borehole lithologic logs indicate that soils range from coarse sands to silty clays. An impermeable clay layer fixes the bottom of the upper aquifer at approximately 7.5 m (25 ft).

Water-table elevations have been monitored at wells and piezometers around the facility to determine the direction of groundwater flow. The Lower Diagonal No. 1 Drain forms a groundwater boundary along the northern edge of the facility. Periodic monitoring of surface-water flow elevations indicates the ditch is either a "gaining" or "losing" stream depending on seasonal flow rates. The nearby potentiometric surface is thus affected by the periodic fluctuations in surface-flow elevation. The potentiometric surface contours shown in Fig. 10 indicate an average potential gradient of 0.0013, which induces a general flow to the southeast.

Two pumping tests and twelve bail tests have been performed on groundwater wells in and around Site 2. Wells tested were completed in different portions of the aquifer, thus providing insight into aquifer heterogeneity. Pumping tests were conducted on ERM-West well W-20 and on a 13-cm (5-in.) pumping well, PW1, installed near MW04 (Fig. 11). A coarse-grained sandy unit was specifically chosen as the location for PW1 in order to determine the maximum hydraulic conductivity associated with the site.

The pumping test conducted at PW1 yielded a transmissivity of 32.5 cm^2/s (22,900 gal/day/ft) and a storativity of 0.022. The resulting hydraulic conductivity was calculated to be 7.7×10^{-2} cm/s (1640 gal/day/ft^2). Assuming an effective porosity of 0.2 and an average potential gradient of 0.0013, linear groundwater velocity

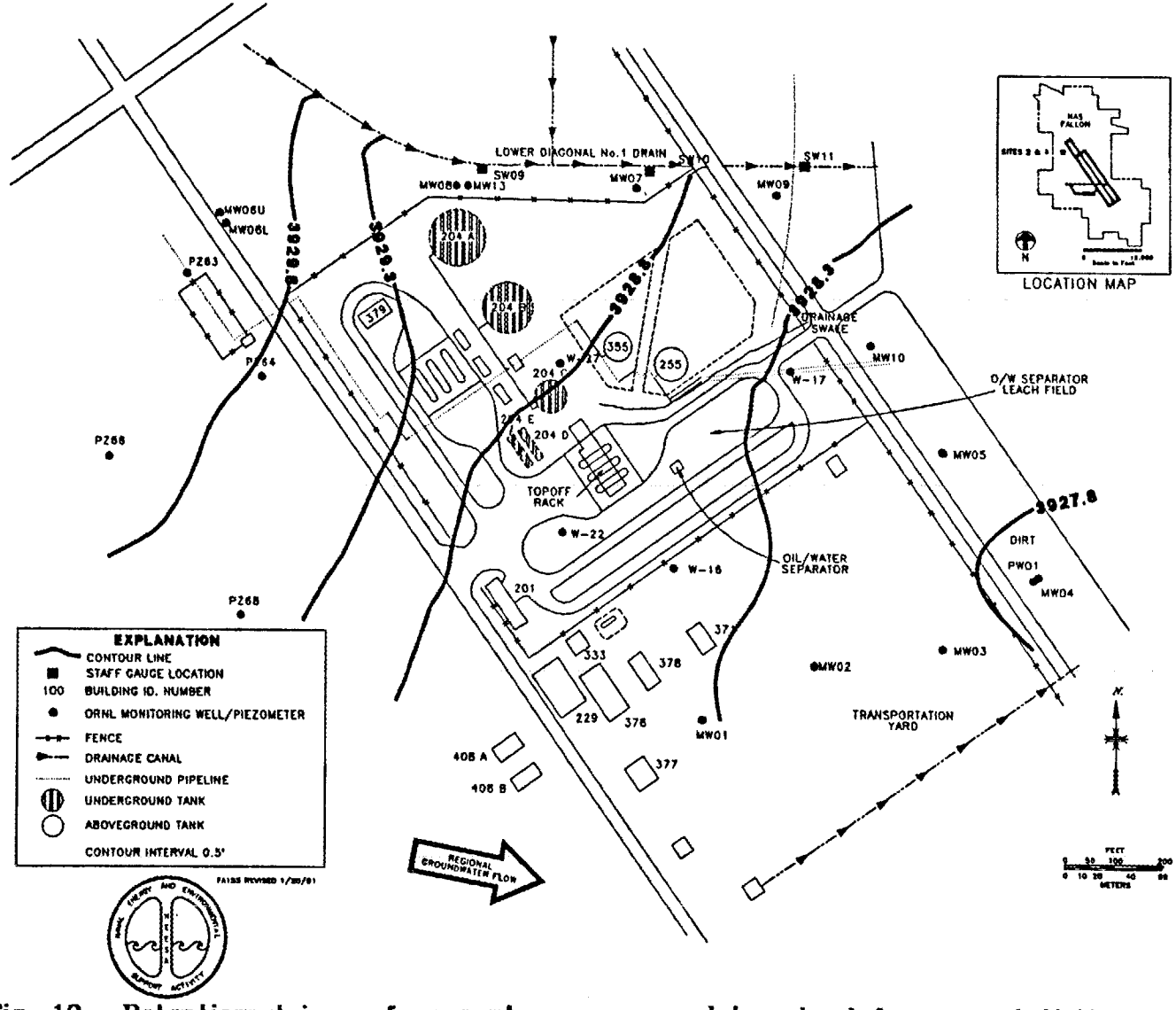


Fig. 10. Potentiometric surface contour map as determined from geostatistical interpretation based on 20 potentiometric head measurements taken August 1990. Group I Sites: Site 2, New Fuel Farm, and Site 4, Transportation Yard.

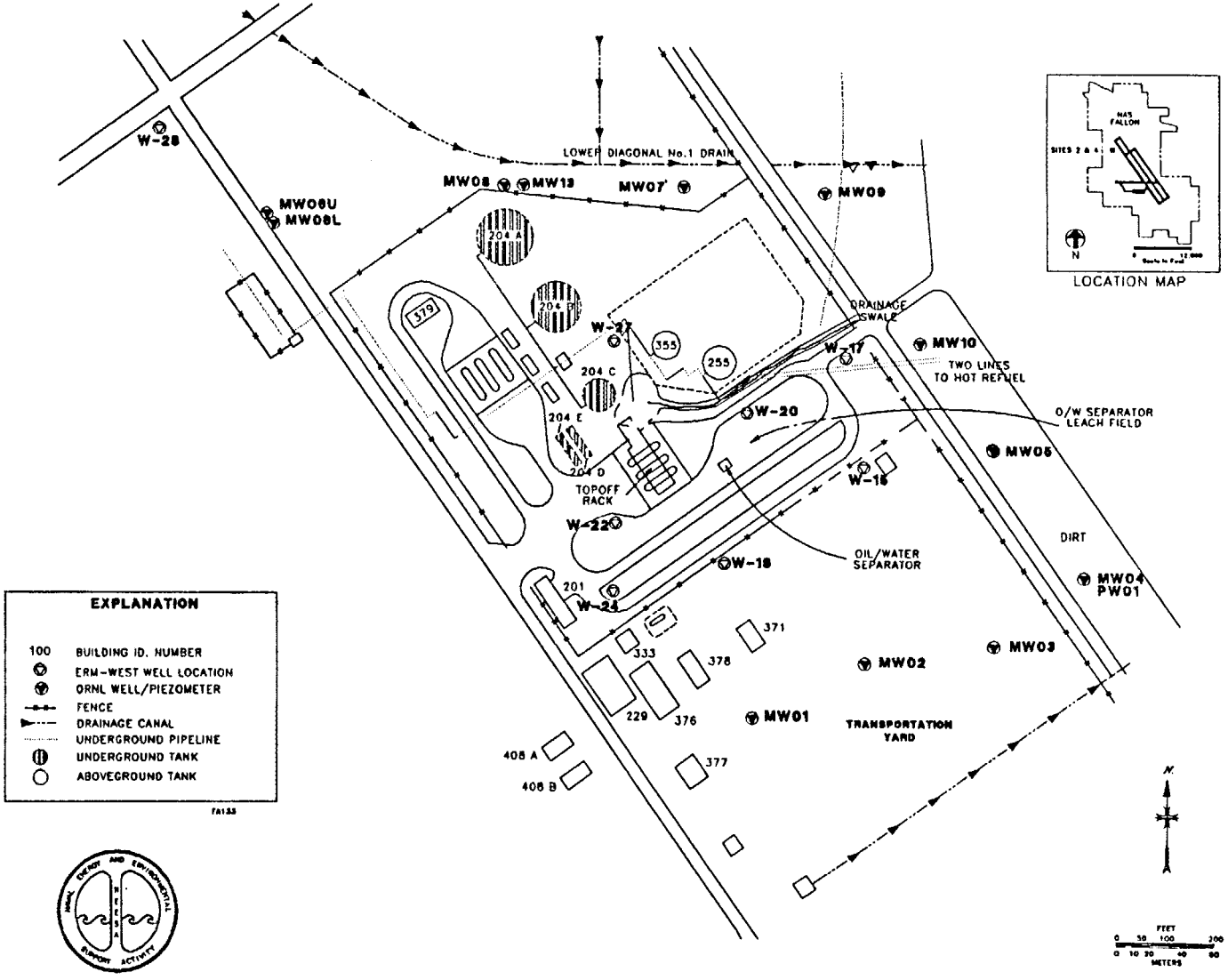


Fig. 11. ERM-West and ORNL monitoring well location map. Group I Sites: Site 2, New Fuel Farm, and Site 4, Transportation Yard.

is estimated to be 0.43 m/day (1.425 ft/day) or 157.6 m/year (520.5 ft/year) for the screened interval of this well. Similar calculations for W-20 resulted in a transmissivity of 8.3 cm^2/s (5840 gal/day/ft), a storativity of 0.014, a hydraulic conductivity of 1.8×10^{-2} cm/s (390 gal/day/ft^2), and a linear groundwater velocity of 0.1 m/day (0.339 ft/day) or 37.5 m/year (123.8 ft/year).

Table 8 summarizes results from the pumping tests and bail tests conducted at Site 2. For comparative purposes, identical parameters (porosity of 0.2 and average potential gradient of 0.0013) were used for all average linear flow velocity calculations.

The pump and bail tests indicate a heterogeneous aquifer comprised of areas of high hydraulic conductivity separated by intermittent zones of less-permeable material. Hydraulic conductivity values appear to vary over at least two orders of magnitude. The fence diagram (Fig. 12) shows the relationship of various zones with respect to well locations. The presence of areas with high permeabilities suggests the potential for off site transport if hydraulic communication is established between these areas and areas of known contamination.

As discussed above, sampling of surface waters and residential wells near Site 2 gave no indication that contaminants have been transported off site. In addition, site-characterization activities indicate that contaminants at Site 2 are relatively immobile, being contained in the shallow subsoils. These observations indicate: 1) subsurface conditions are preventing contamination from entering zones of high flow potential, or 2) groundwater-flow rates in high flow zones are diluting contaminants to concentrations below detection limits. Additional investigations are necessary to determine the extent, location, and continuity of high flow zones as well as migration pathways between these zones and known contaminant source areas.

Table 8. Hydrological parameters - ORNL/GJ investigation

HYDROLOGICAL PARAMETERS					
Test Method	Well Number	K[a] Test 1	K Test 2	K Average	Average Linear Velocity, ft/year
Bail test	MW02	64	61	62.5	19.8
	MW03U	63	56	59.5	18.9
	MW03L	46	66	56	17.8
	MW04	***	***	***	Not Done
	MW05U	60	Not Done	60	19
	MW05L	53	59	56	17.8
	MW06U	32	40	36	11.4
	MW07	***	***	***	Not Done
	MW08	15	17	16	5.1
	MW09	19	13	16	5.1
	MW10	19	17	18	5.7
Pump test	W-20 (ERM-West results)	390	Not Done	390	123.8
	PW1	1,640	Not Done	1,640	520.5

[a] K = hydraulic conductivity, gal/day/ft^2
*** indicates that well recovery was too rapid for an accurate test.

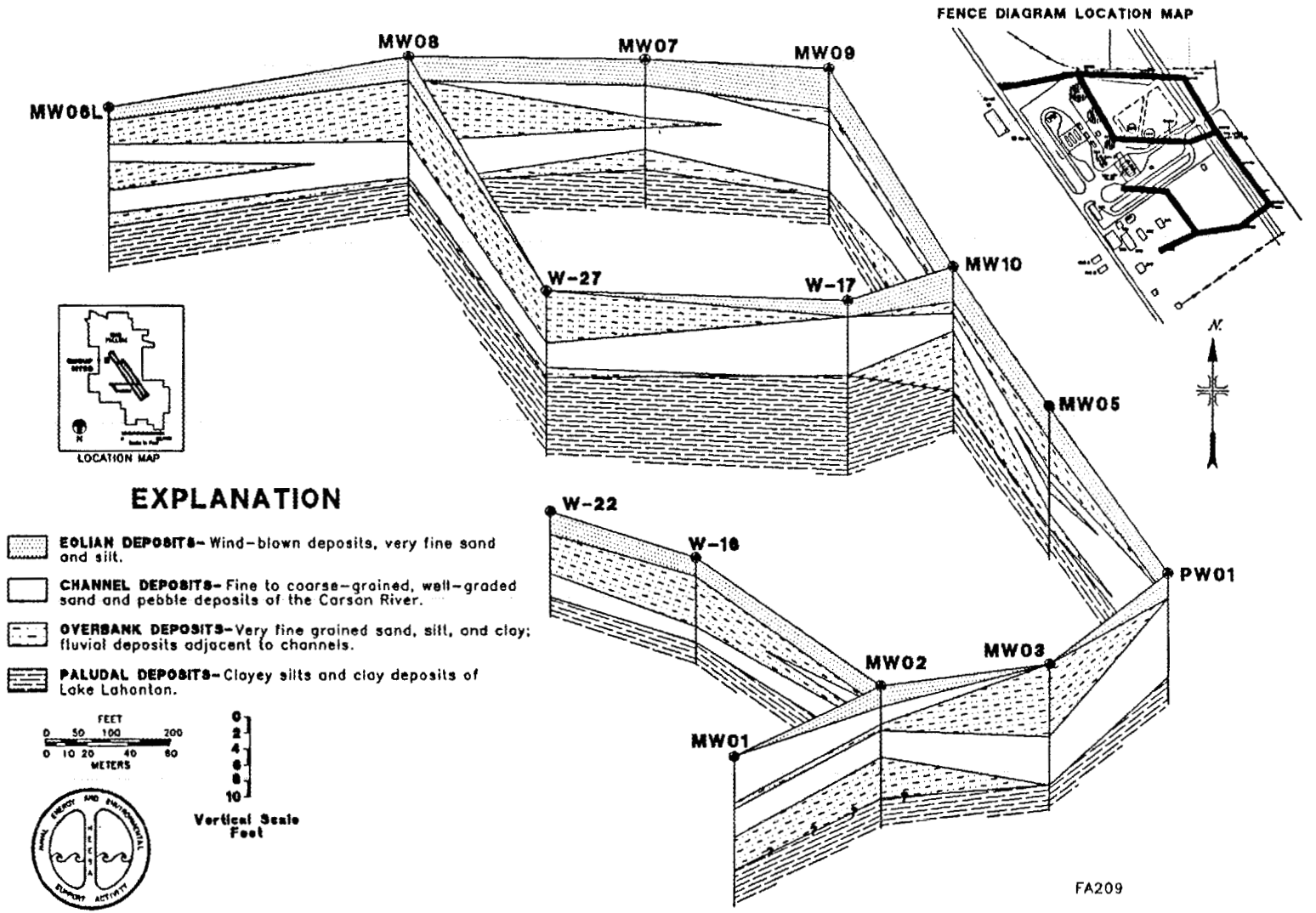


Fig. 12. Fence diagram of selected Group I wells.

Exposure Points and Affected Biota

Potential environmental exposure methods and receptors associated with contaminants at Site 2 include:

- ingestion, inhalation, and dermal contact by authorized personnel with free product, contaminated soils, and contaminated groundwater through exposures during construction, maintenance, or remedial activities;

- ingestion, inhalation, and dermal contact by persons and/or biota with contaminated surface waters culminating at the Stillwater National Wildlife Refuge; and

- ingestion, inhalation, and dermal contact by persons or livestock utilizing contaminated water from groundwater wells affected through off-site transport.

In addition, secondary exposures may be facilitated through ingestion of contaminated biota consumed through the food chain.

APPLICABLE OR RELEVANT AND APPROPRIATE REQUIREMENTS (ARARs)

Petroleum hydrocarbons are the contaminants of concern at Site 2. The State of Nevada Division of Environmental Protection Hydrocarbon Cleanup Policy as amended by the Proposed Regulation of the State Environmental Commission (LCB File No. R083-90, effective 10-1-90) specifies action levels for hydrocarbon contamination. The following statements regarding soil removal, dissolved product, and free product are direct excerpts from that document (NDEP 1987).

Soil Removal

The Division of Environmental Protection (DEP) may require soil removal if total petroleum hydrocarbon concentrations (TPH) in the soils are in excess of 100 mg/kg (ppm) as determined by Environmental Protection Agency (EPA) method 8015 as modified for petroleum hydrocarbons. The determination of removal shall be based upon the following site specific information:

1. *Depth to groundwater: Depth to the nearest occurrence of water saturated soils. This includes perched water;*

2. *Quality and use of the affected groundwater: Inorganic and organic quality as well as present use and potential use of the aquifer for drinking water, irrigation, etc.;*

3. *Distance to the nearest drinking water well: Distance to the nearest well irregardless of gradients. Is the well presently used for drinking water purposes and what is the estimated number of users?;*

4. *Soil type and estimated permeability: Types of soils encountered throughout the profile to groundwater in terms of it's texture, permeability, homogeneity, etc. is a major factor in migration velocity, attenuation and the potential for groundwater contamination;*

5. *Annual precipitation: Annual precipitation, annual evaporation, precipitation type (snow, rain) and potential for short term, high intensity events are all parameters which may influence the driving forces for contaminant migration.*

6. *Age and condition of the hydrocarbon contaminant: The age of the product and its amount of degradation has a direct bearing on the potential for the migration of that product as well as future negative impacts to groundwater and public health and safety;*

7. *Extent of the contaminated area (vertical and horizontal): A determination of the extent of contamination must include definition of both soil and groundwater contamination. This can be accomplished by the use of wells, soil-gas surveys, ect.;*

8. *Present and future land use: Present and proposed land use is a major factor in determining the level of remediation needed for a given parcel is subject to;*

9. *Migration potential via preferential routes (i.e. utility lines, road base, conduits, etc.): These routes can drastically affect the movement and occurrence of product in the subsurface environment and can have direct impacts to public health and safety;*

10. *Hydrocarbon product type: Product type has a direct bearing on the type of remediation proposed. Due to the volatility of some products, remediation can be accomplished via simple venting of the soils whereas other products may require removal or other methods of remediation. This also has a significant bearing on the potential for a dissolved product plume in the groundwater;*

11. *Vapor/explosion/safety hazard: If a safety hazard is identified the DEP will require an immediate remediation of the problem;*

12. *Structural impediments such as foundations, roadways, pipelines, etc. which may impede complete soil removal: In some instances structural impediments make soils removal difficult or impossible. It is the goal of the DEP to make decisions that are reasonable in regard to the cost verses benefits of soil removal in these situations.*

In certain circumstances, the DEP will consider alternatives to soil removal. In situ biodegradation, soil venting and in situ chemical treatment and other methods shall be examined as viable and desirable alternatives to soil excavation and disposal.

Dissolved Product

Dissolved hydrocarbon product may require remediation any time it is encountered in a potable or drinking water quality aquifer and benzene, ethylbenzene, xylene or toluene concentrations are equal to or in excess of EPA recommended maximum contaminant levels (RMCLs) or maximum contaminant levels (MCLs). [Authors' note: The MCL for benzene is 5.0 μg/L. EPA-proposed MCLs for the remaining contaminants are: ethylbenzene - 700 μg/L; xylene (total) - 10,000 μg/L; and toluene - 2,000 μg/L (Leeden 1990).]

Discharge of affected groundwaters to surface waters shall contain no more than 1.0 mg/L TPH. Discharge to a publicly owned treatment works (POTW) shall contain no more than 10.0 mg/L TPH or the POTW discharge limit, whichever is less. Reinjection of affected waters to the groundwater shall be handled on a case by case basis by the DEP.

Free Product

Any time free product is encountered on the groundwater in the formation in excess of one half in. (0.5 in.) (measurement accuracy of 0.01 ft), a recovery action must be undertaken. This action must include delineation of the plume boundaries, characterization of the product and the design and implementation of an extraction/remediation

system. Discharge of affected groundwater and disposal or recycling of recovered product must conform to applicable federal, State and local requirements including fire and building codes.

Identified explosion or vapor hazards must be addressed and remediated immediately.

FREE PRODUCT REMOVAL ACTIONS

GOALS OF FREE-PRODUCT REMOVAL ACTIONS

Characterization data at Site 2 is sufficient to implement free product removal actions at this time. The proposed removal actions address the following environmental and regulatory issues:

1. to design a system that will remove free floating product associated with the site.

2. to utilize knowledge gained through implementation and operation of the removal actions to develop a remedial action strategy consistent with NDEP Orders to Comply and recommendations discussed previously and in accordance with ARARs stated earlier in this document.

The following sections develop and evaluate free-product removal options and discuss the rationale used in developing the recommendations.

DEVELOPMENT AND EVALUATION OF FREE-PRODUCT REMOVAL TECHNOLOGIES

Various technology combinations are available for free-product removal. For initial development, a free-product removal system may be separated into two basic technology types: 1) technologies for providing access to the underlying free product, and 2) technologies for extracting free product once access is established. Technology types will be evaluated in terms of effectiveness, implementability, and cost.

Because evaluation parameters for these two technology types are independent of one another, each category will be evaluated independently to determine the best technology types for Site 2.

Technologies To Access Free Product

Two methods of penetrating the subsurface to allow access to free product will be evaluated. These are: 1) the drilling of recovery wells, and 2) construction of a permeable trench.

The recovery-well technique consists of drilling one or more wells into the affected area from which free product can be removed. Hydrologic parameters of the area dictate the number and spacing of wells to ensure that the withdrawal radius of the wells effectively covers the site. In this manner, free-product recovery from the entire contaminated area is achieved.

The trench technology consists of excavating soil from the contaminated area to a depth sufficient to expose the underlying free product. The open pit is then backfilled with permeable backfill and manholes installed to provide access to the free product at depth. Free product is then removed from the manholes. The permeability of the backfill determines the number and spacing of manholes necessary to effectively cover the area of the excavated pit. Evaluation parameters concerning the effectiveness, implementability, and cost of these technologies are discussed below.

RECOVERY WELLS

Effectiveness

An accurate assessment of the underlying hydrologic parameters is necessary to design an effective well field recovery system. Heterogeneities, preferential flow paths, and permeabilities must be well-documented to allow the well field's radius of influence and withdrawal rates to effectively remediate the contaminated area. Recovery wells

are thus most effective when placed in a well-characterized homogeneous environment of high permeability.

Implementability

Implementability for a well field removal system is very good. Safe, effective technologies are available for well installation in a variety of environments. Permitting procedures and institutional implementability are also common practice and routinely achieved.

Cost

Typical recovery-well costs may be estimated at $100/ft. The total cost of the recovery system is related to the depth of penetration and the underlying hydrology. On a cost-per-foot basis, the total cost of the well field is directly proportional to the depth to free product. Heterogeneous, less-permeable environments increase costs by necessitating a larger number of more closely spaced wells in order to effectively cover the site.

PERMEABLE TRENCH

Effectiveness

A permeable trench is very effective for free-product removal. Underlying hydrologic parameters are not a major consideration in trench design because the permeable medium of the trench encompasses a much larger area than an equivalent well system. Recovery rates and the radius of influence are thus a function of the known hydrologic parameters of the backfill rather than the native subsoil. Preferential flow paths and heterogeneities are more easily intercepted because the trench perimeter establishes contact with a much larger area of the subsurface. This larger contact area also increases free-product recovery rates because more of the porous subsoil is exposed to a high-permeability medium.

The implementation of a trench recovery system requires the removal of substantially more native subsoil than an equivalent well field recovery system. Because of this fact, the trench is more effective in removing residual contaminants which may exist in the overlying surface soils. Once excavated, contaminated soils may be effectively treated or contained. This advantage is somewhat offset by the clean backfill becoming contaminated as free product is removed. Nonetheless, the high permeability and known spatial extent of the permeable backfill make it much more conducive to *in situ* remediation, e.g., bioremediation, soil flushing, or steam stripping, once free-product removal has been completed.

Finally, a trench system is also very effective in providing additional site characterization information during the implementation stage. As the system is installed, the open pit provides easy access to the subsurface environment. Visual inspections and sampling may be conducted to reassess removal-system design parameters as the excavations progress. Important design parameters such as permeability and overall size of the trench recovery system may be changed as work progresses to ensure an efficient overall system. The trench system thus provides design flexibility and is more effective for removal systems in heterogeneous, less-permeable environments with complex hydrology.

Implementability

Implementability for a trench removal system is limited to shallow recovery systems, i.e., 6 m (20 ft) or less. Techniques are readily available for the implementation of these shallow systems. Conversely, safety and practical implementability concerns associated with caving and sluffing become excessive at greater depths. While shoring and slurry wall techniques are available for deep recovery trenches, implementability is still difficult.

Cost

Typical trench recovery system costs may be estimated at $100/m^3 ($80/yd^3). The total cost of the recovery system is established by the spatial extent of the excavation, usually 100-200 yd^3. Costs are relatively independent of the underlying hydrologic conditions but do increase dramatically with depth when safety and implementability are considered.

Table 9 shows a comparative analysis between a well field removal system and a trench system in light of the subsurface conditions associated with Site 2. As seen in Table 9, shallow depths, heterogeneous flow conditions, overlying residual soil contamination, and faster recovery rates indicate that the permeable-trench recovery method is preferable at Site 2.

Technologies For Free-Product Extraction

Once contact with the underlying free product has been established, technologies must be implemented for active extraction. Extraction techniques may be separated into those which remove product as it is encountered in its natural state of floating on the water table and those which enhance extraction efficiency through some form of gradient alteration. Single recovery systems are included in the first type and skim free product off the water table leaving the underlying groundwater undisturbed. Enhanced recovery through gradient alteration is accomplished by either dual recovery systems or some type of groundwater mounding caused by addition of groundwater in the surrounding area.

Table 9. Comparative analysis - Technologies to access free product

Comparative Analysis - Technologies to Access Free Product Site 2, NAS Fallon		
Evaluation Criteria	Technology Types	
	Well Field	Permeable Trench
Effectiveness	Poor: the heterogeneous flow patterns resulting from past meandering stream channels which underlie the site are not conducive to a well field removal system.	Excellent: the system is well suited to heterogeneities which may underlie the site. Contaminated subsoils will be removed during installation. Free-product extraction rates will be increased and knowledge gained during implementation.
Implementability	Moderate: the shallow depth to free product lends itself well to implementation, but complex hydrology will make effective design difficult.	Excellent: the shallow depth to free product facilitates implementation, and the trench technique is flexible enough to adapt to unanticipated hydrologic conditions encountered.
Cost	Moderate: the shallow water table and easy accessibility of the site should make installation relatively inexpensive. Slow recovery rates will mandate longer recovery times and, hence, increase operational costs.	Excellent: the shallow water table and faster recovery rates permit cost effective removal of free product.

Dual recovery systems utilize free-product skimming in conjunction with removal of the underlying groundwater. The groundwater removal results in a cone of depression which creates an enhanced pressure gradient on the surrounding free-product. The altered gradient causes free product to migrate to the depression cone, thus increasing the efficiency of free-product recovery. Extracted groundwater is remediated and disposed of by either reinjection or some form of surface discharge.

Groundwater mounding also relies on enhancing the migration rate of free product to increase extraction efficiency. Unlike the depression cone created by the dual recovery system, groundwater mounding raises the water table in the surrounding area to increase product migration towards the extraction system.

The primary difference between the two gradient-alteration techniques lies in the symmetry of the resulting product-migration front. Because the dual recovery system uses point withdrawal to create the depression cone, the product-migration pattern is radially symmetric about the extraction point. This migration pattern ensures that product is directed towards the extraction point, and free-product extraction efficiency is enhanced. Conversely, the groundwater-mounding scheme raises the surrounding water table by some type of injection or infiltration into the underlying groundwater. Maintaining a migration pattern towards the extraction point is very difficult with this technique because injection is usually accomplished with upgradient wells or infiltration line sources. The resulting groundwater mound results in a linear product front which migrates downgradient. This broad migration front is much more difficult to intercept and control than the radially symmetric front produced by the dual recovery system. As such, groundwater mounding enhanced recovery should be restricted to a permeable-trench system which encompasses an area sufficient to guarantee product interception and recovery. In addition, site conditions should be such that impermeable or constant-head boundaries provide additional control over product migration. Under these conditions, groundwater mounding may be an effective, enhanced-recovery technique.

Evaluations of the effectiveness, implementability, and cost of single recovery systems, dual recovery systems, and groundwater-mounding techniques are presented below.

SINGLE RECOVERY SYSTEMS

Effectiveness

Single recovery systems are most efficient in areas exhibiting high permeability and large amounts of floating product. Recovery rates are, however, limited by the natural gradients of the surrounding system; operational times are correspondingly longer than comparable dual recovery or groundwater-mounding recovery systems. Likewise, the recovery radius is also limited by indigenous gradients, and recovery systems must be more closely spaced to effectively remove free product. As product thickness decreases, some type of gradient alteration is often required to facilitate the last 10 to 20% of free-product removal.

Implementability

Single recovery systems are easily implemented.

Cost

The cost of implementing a single recovery system is minimal in comparison with a dual recovery system. Conversely, operational and maintenance costs are greater due to the slower recovery rates and longer operational time required to remove product.

DUAL RECOVERY SYSTEMS

Effectiveness

Dual recovery systems are very effective for removing free product. The cone of depression created by groundwater removal increases both extraction rates and extraction efficiencies. In addition, dissolved contaminants may be removed through the groundwater-extraction process.

Implementability

Dual recovery systems are easily implemented from a technical point of view. Institutionally, implementation is more difficult because of permitting requirements associated with disposal of the extracted groundwater. A NPDES permit or compliance with POTW pretreatment limitations may be required for surface discharge of treated groundwater. The permitting process for reinjection can also be a complicated procedure requiring extensive documentation of the subsurface hydrology.

Cost

Dual recovery systems are more costly to implement than single recovery systems because of the additional cost associated with treatment of the extracted groundwater. These costs are somewhat off-set by reduced operational and maintenance costs associated with the faster, more efficient recovery rates inherent in the system.

GROUNDWATER MOUNDING

Effectiveness

Groundwater mounding can be an effective technique for enhancing product migration. Unfortunately, the technique does not provide good directional control of the enhanced migration pattern. In order to ensure that migrating product is intercepted and removed, groundwater mounding should be restricted to use with a permeable-trench system capable of intercepting product flow. It is also advisable to restrict use to sites where existing hydrologic boundaries (both impermeable and constant head) further contain and limit product-migration potential. Under these conditions, groundwater mounding is an effective and usable technology for enhanced recovery.

Implementability

Groundwater mounding is an implementable technology if site conditions are conducive to controlling the resulting contaminant migration pattern.

Cost

The cost of implementing groundwater mounding depends on site conditions and the availability of a water source to effect the groundwater mound.

Table 10 shows a comparative analysis of single-recovery, dual-recovery, and groundwater-mounding technologies in light of the parameters associated with Site 2. As indicated in the notes of Table 10, the preferred extraction technology for Site 2 is a single recovery system if groundwater mounding is a viable option to enhance recovery rates. Because site conditions at Site 2 are favorable for

Table 10. Comparative analysis - Free-product extraction technologies

Comparative Analysis - Free-Product Extraction Technologies Site 2, NAS Fallon			
Evaluation Criteria	Technology Types		
	Single Recovery	Dual Recovery	Groundwater Mound
Effectiveness	Good: Recovery rates are slower and require additional operating and maintenance costs. Note: Excellent if enhancement is possible with groundwater mounding.	Excellent: the technology is conducive to fast, efficient removal of the thinner layers of floating product at the site.	Excellent: the constant head boundary formed by No. 1 Drain combined with the permeable-trench system make this technology ideal. Drain also serves as good source for water.
Implementability	Excellent: no apparent problems.	Moderate: effluent discharge permits for treated groundwater may complicate implementation.	Excellent: no apparent problems.
Cost	Good: inexpensive installation costs will off-set the longer operational costs. Note: Excellent if enhancement is possible with groundwater mounding.	Poor: excessive costs associated with groundwater treatment and discharge make this alternative undesirable.	Excellent: site-specific parameters and good availability of water source make this alternative cost effective to implement.

groundwater-mounding enhancement, the preferred extraction technology for recovery of free product is a single recovery system combined with enhanced recovery through groundwater mounding.

DEVELOPMENT OF ALTERNATIVES FOR FREE-PRODUCT REMOVAL

The above indicates that the preferred technologies for assembling free-product removal options are: 1) use of a permeable trench to provide access to the underlying free product, and 2) use of a single recovery system combined with enhanced recovery through groundwater mounding to extract free product. Free-product removal alternatives composed of these technology types are assembled below. A "No Action" alternative will also be considered.

ALTERNATIVE I - NO ACTION

Alternative I, "No Action", will consist of continued monitoring of the magnitude and extent of free product underlying the facility. Because NAS Fallon is a restricted area, no additional access restrictions will be imposed.

ALTERNATIVE II
PERMEABLE TRENCH/SINGLE RECOVERY PNEUMATIC PUMP/GROUNDWATER MOUNDING

Alternative II, Permeable Trench/Single Recovery Pneumatic Pump/Groundwater Mounding, will access the underlying free product through use of a permeable trench as described earlier. A single recovery system using a low-volume pneumatic pump will be used to extract free product which accumulates in the collection trench. Extraction rates will be enhanced by raising the water level in the

Lower Diagonal No. 1 Drain to create a groundwater mound upgradient from the recovery system. Free product will thus be effectively trapped between the drain and extraction trench, and the groundwater mound will force product flow towards the removal system.

ALTERNATIVE III

PERMEABLE TRENCH/FLOATING SKIMMER PUMP/GROUNDWATER MOUNDING

Alternative III, Permeable Trench/Floating Skimmer Pump/Groundwater Mounding, is similar to Alternative II. Underlying free product will be accessed using a permeable trench, and enhanced recovery through groundwater mounding will be employed as described above. This alternative differs in that a single recovery system using a floating skimmer pump will be used to extract the underlying product.

EVALUATION OF FREE-PRODUCT REMOVAL ALTERNATIVES

The three alternatives will be evaluated with respect to effectiveness, implementability, and cost. Alternatives will be evaluated individually prior to collective evaluation.

Individual Alternative Evaluation

ALTERNATIVE I - NO ACTION

Effectiveness

Alternative I, "No Action", is not effective in meeting the goals of free-product removal actions described earlier. The alternative does not conform to action levels as specified in the NDEP hydrocarbon clean-up policy. In addition, implementation of the alternative will not

provide any additional knowledge regarding an overall cleanup policy for the site.

Implementability

The alternative will be very difficult to implement institutionally because of its overall ineffectiveness.

Costs

Costs associated with this alternative include sampling and analytical expenses necessary for continued monitoring, as well as fines resulting from not responding to the NDEP Order to Comply. Because litigation will eventually determine the total cost for imposed fines, cost estimates, shown below, are given on a per-day basis.

Cost Estimates - Alternative I

Monitoring

Monitoring estimates based on quarterly sampling of ten sample locations at $500.00/sample for 20 to 30 years	
Total Monitoring Estimate (20 to 30 yr)	$400,000 - $600,000

Fines

Pursuant to NRS 445.331, any person who violates a final order issued under any provision of NRS 445.131 to 445.354 inclusive is subject to a civil penalty of not more than $25,000 for each day of violation	$25,000/day

ALTERNATIVE II

PERMEABLE TRENCH/SINGLE RECOVERY PNEUMATIC PUMP/GROUNDWATER MOUNDING

Effectiveness

Alternative II is effective in meeting the removal goals described earlier. The technologies used in this alternative facilitate free-product removal in accordance with the NDEP action level of 1.27 cm (0.5 in.).

Installation of the permeable trench will provide additional information regarding the magnitude and extent of existing contaminants at the site. Enhanced recovery via groundwater mounding will result in the additional benefit of preventing product seepage into the Lower Diagonal No. 1 Drain. The permeable trench also easily adapts to using a dual recovery system and/or *in situ* remediation of the trench backfill as future conditions dictate. The alternative thus exhibits good potential for using additional removal/corrective measures.

Effectiveness is decreased as the product layer thins and approaches the thickness of the pneumatic pump's inlet chamber. Effective removal of thin product layers requires extensive monitoring and lowering of the pump inlet position to ensure that it remains in the zone of free product. As free-product layers thin, an oil/water filter may have to be employed to prevent groundwater removal if free-product removal to a "sheen" thickness is desirable.

Implementability

The alternative's effectiveness combined with the absence of permitting requirements for handling contaminated groundwater favor institutional implementability. Technical implementability is also excellent with conventional technologies readily available for installation and operation of the alternative.

Cost

Estimates of installation and yearly operational costs for Alternative II are shown below.

Installation estimates include: 1) implementation of groundwater-mounding enhanced recovery through gradient alteration in the Lower Diagonal No. 1 Drain, and 2) installation of four extraction trenches, each encompassing a volume of 76 m^3 (100 yd^3). An access manhole, low volume pneumatic extraction pump, 380-L (100-gal) storage tank, and associated piping/electrical wiring are also included for each recovery trench.

Yearly operational expenses include estimates of the monitoring, adjustment, and maintenance costs necessary to operate the system. Because the low-volume pneumatic pump is not self-regulating with respect to the depth of free product in the trench, regular monitoring and adjustments are necessary to ensure that the pump intake is positioned in the free-product layer. Maintenance includes periodic emptying of the 100-gal storage tanks associated with each extraction trench.

Cost Estimates - Alternative II

Installation

Gradient alteration of the Lower Diagonal No. 1 Drain.....	$8,000
Installation of four 76-m^3 (100-yd^3) extraction trenches and associated product extraction equipment at $23,500/ea.....	94,000
Total Installation Estimate.....	$102,000

Yearly Operational Costs

Monitoring and adjustments expense: 780 man-hours/yr at $35.00/man-hour.....	$27,300
Maintenance expense: 200 man-hours/yr at $35.00/man-hour.....	7,000
Total Yearly Operational Estimate.....	$34,300

ALTERNATIVE III

PERMEABLE TRENCH/FLOATING SKIMMER PUMP/GROUNDWATER MOUNDING

Effectiveness

Alternative III is effective in meeting the removal goals. The technologies used in this alternative facilitate free-product removal in accordance with the NDEP action level of 1.27 cm (0.5 in.). Installation of the permeable trench will provide additional information regarding the magnitude and extent of contaminants at the site. Enhanced recovery via groundwater mounding will result in the additional benefit of preventing seepage discharge of product into the Lower Diagonal No. 1 Drain. The alternative's permeable trench adapts easily to a dual recovery system and/or *in situ* remediation of the trench backfill as future conditions dictate. The alternative thus exhibits good potential for implementation of additional removal/corrective measures. The skimmer pump used for extraction is capable of effectively removing free product to a "sheen" thickness.

Implementability

The alternative's effectiveness combined with the absence of permitting requirements for handling contaminated groundwater favor

institutional implementability. Technical implementability is also excellent, with conventional technologies readily available for installation and operation.

Cost

Estimates of installation and yearly operational costs for Alternative III are shown below.

Installation estimates include: 1) implementation of groundwater-mounding enhanced recovery through gradient alteration in the Lower Diagonal No. 1 Drain; and 2) installation of four extraction trenches, each encompassing a volume of 76 m^3 (100 yd^3). An access manhole, floating skimmer extraction pump, 380-L (100-gal) storage tank, and associated piping and electrical wiring are also included for each recovery trench.

Yearly operational expenses include estimates of the monitoring, adjustments, and maintenance costs necessary for operation of the overall system. The floating skimmer pump is self-regulating with respect to the depth of free product in the trench; thus, monitoring and adjustments necessary for effective operation are minimal. Maintenance includes periodic emptying of the 100-gal storage tanks associated with each extraction trench.

Cost Estimates - Alternative III

Installation

Gradient alteration of the Lower Diagonal No. 1 Drain.....	$8,000
Installation of four 380-L (100-yd^3) extraction trenches and associated product extraction equipment at $27,500/ea.....	110,000
Total Installation Estimate.....	$118,000

Yearly Operational Costs

Monitoring and adjustments expense: 120 man-hours/yr at $35.00/man-hour.....	$4,200
Maintenance expense: 200 man-hours/yr at $35.00/man-hour.....	7,000
Total Yearly Operational Estimate.....	$11,200

Collective Evaluation of Free-Product Removal Alternatives

A comparative analysis of the different alternatives for free-product removal is shown in Table 11. Alternative I, "No Action", is clearly the least preferred because of its ineffectiveness in meeting the removal goals. Alternative III is preferable to Alternative II based on its effectiveness and the operational cost savings incurred from using the self-regulating floating extraction system.

RECOMMENDATION OF PREFERRED FREE-PRODUCT REMOVAL ALTERNATIVE

The preferred free-product removal alternative is Alternative III, Permeable Trench/Floating Skimmer Pump/Groundwater Mounding. A detailed description of the preferred alternative follows.

As shown in Fig. 8, free product is known to exist in five areas at Site 2, based on analytical screening results discussed earlier. Because little confirmed knowledge is available concerning the interconnectedness of these plumes, four free-product removal systems should be implemented as shown in Fig. 13. The contaminated area southwest of underground tank 204C will be addressed through its central location in the extraction network. The four trench extraction systems are positioned to coincide with known source areas or areas of high contamination as determined from field screening and analytical sampling

Table 11. Comparative analysis - Free-product removal alternatives

Comparative Analysis - Free-Product Removal Alternatives Site 2, NAS Fallon			
Evaluation Criteria	Alternative		
	Alternative I No Action	Alternative II Permeable Trench/ Pneumatic Pump/ Groundwater Mound	Alternative III Permeable Trench/ Skimmer Pump/ Groundwater Mound
Effectiveness	0 - unacceptable	4 - good (limited removal for thin layer)	5 - excellent
Implementability	0 - unacceptable	5 - excellent	5 - excellent
Cost	1 - poor	4 - good (additional cost of operation)	5 - excellent (reduced operational cost)
Overall Score High - Prefer Low - Not Prefer	1	13	15

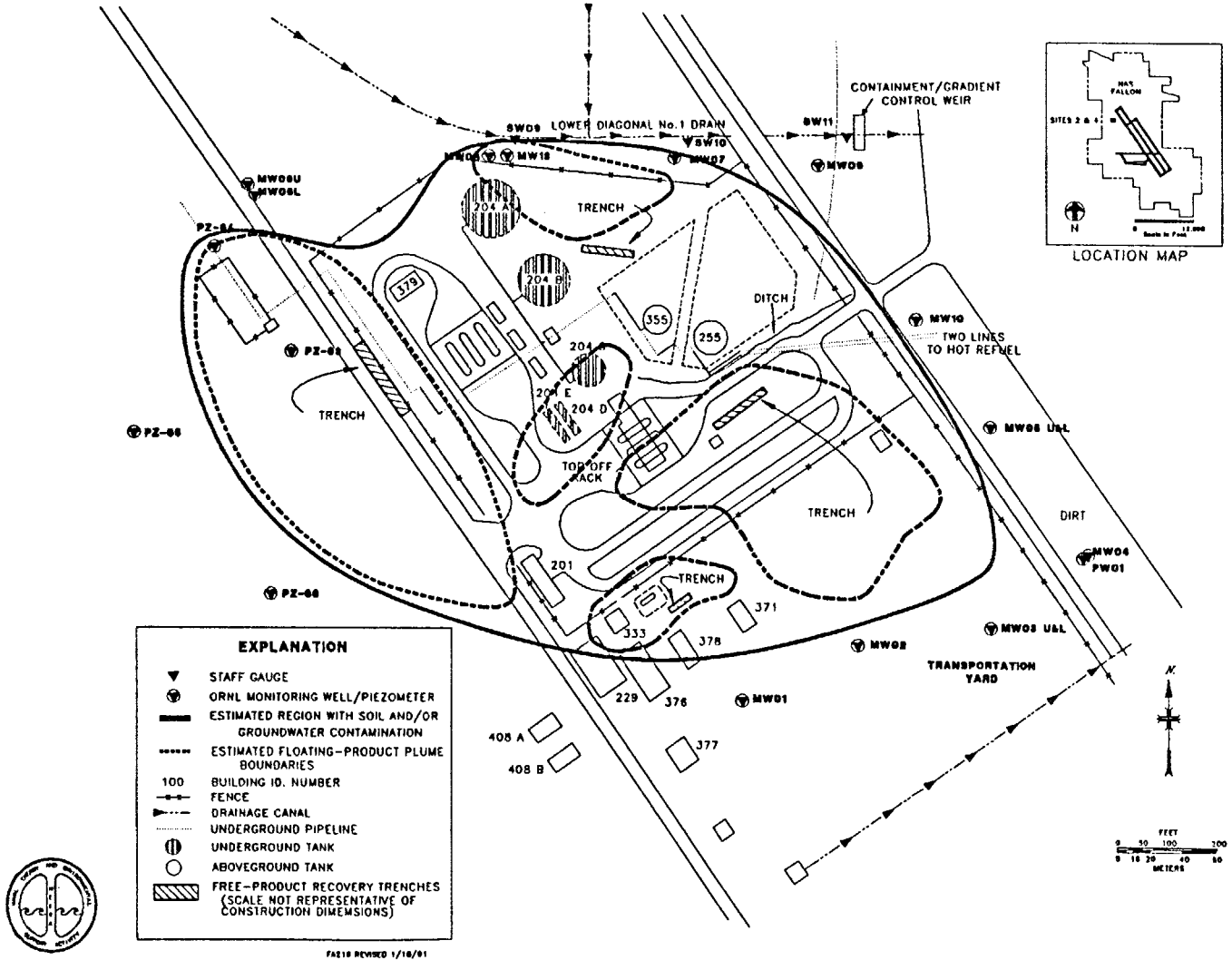
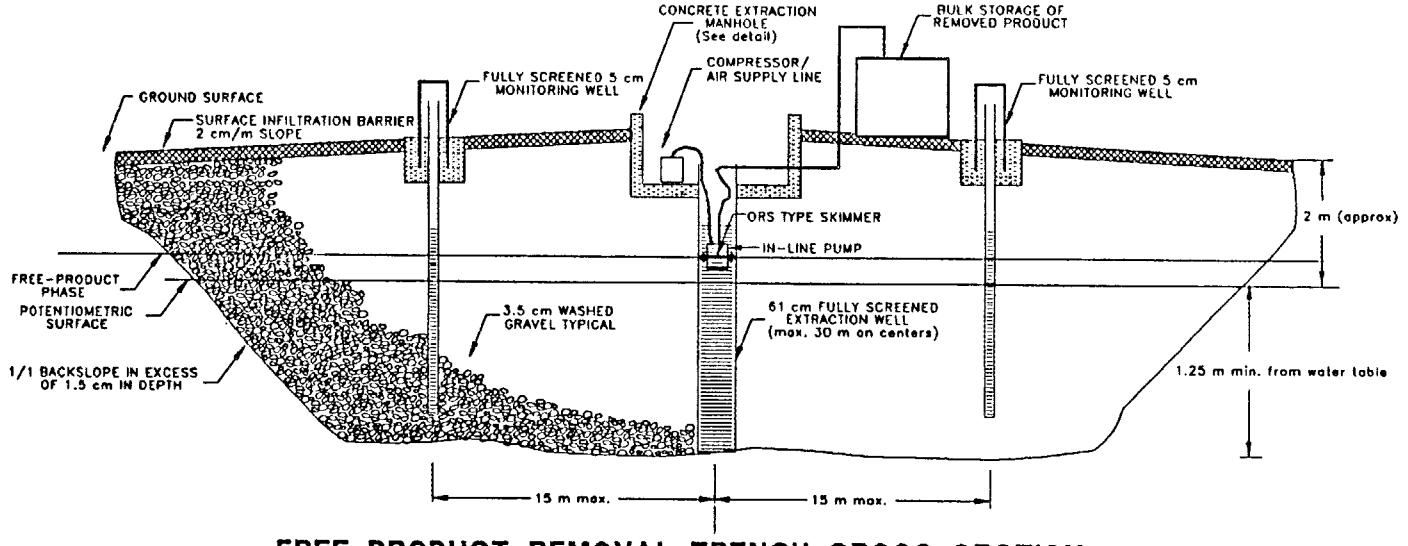


Fig. 13. Group I Sites: Site 2, New Fuel Farm, and Site 4, Transportation yard. Location of interim protective measures.

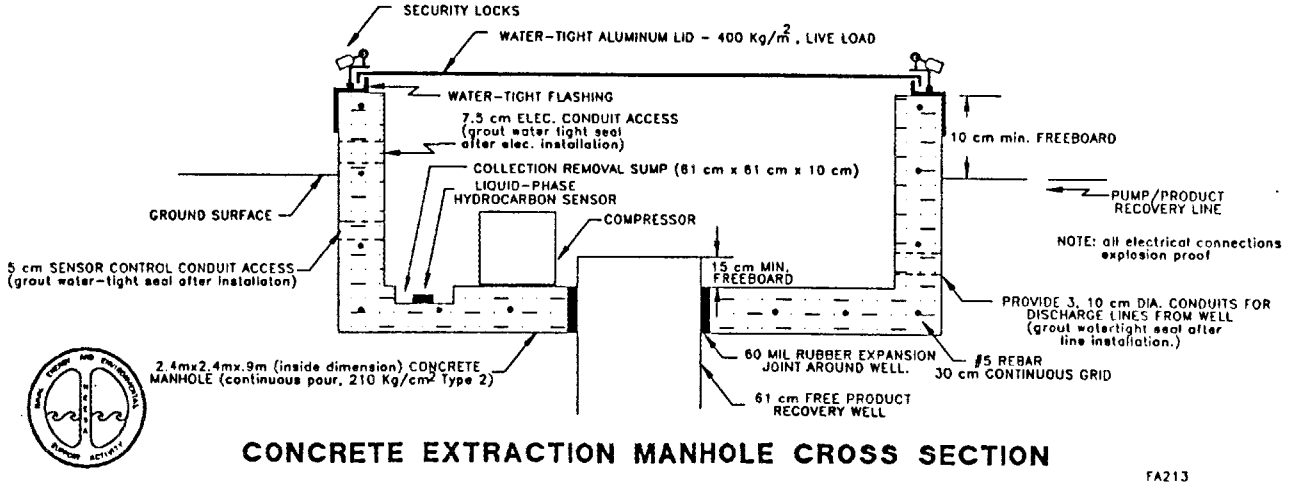
results (ERM-West 1988; NDEP 1990; ORNL/GJ 1989). In this manner, benefits gained from indirect source removal during implementation may be maximized. Trench orientation will be based on surrounding surface structures, contaminant concentrations disclosed during implementation, and the regional groundwater flow.

A cross section of the proposed free-product removal system is shown in Fig. 14. The lateral extent of the trench will be sufficient to encompass removal of excessively contaminated subsoils. If pervasive soil contamination becomes evident during installation, the size of the extraction trench will be reassessed. This assessment will be based on sampling of excavated soil and an analysis of trench size versus product-recovery efficiency as the installation proceeds. While lateral extent should be well defined in the case of the oil/water separator leach field source, a definite source boundary may not be as easily delineated in areas where natural gradients have caused contaminant spreading. For areas where lateral determinations are questionable or soil contamination is widespread, a trench area of approximately 40 m^2 (435 ft^2) will suffice. Depth of excavation should be carried out to a minimum of 1.25 m (4 ft) below the existing water table. This is necessary to assure removal efficiency if the natural water table drops or if dual recovery systems are employed at a later date.

Any contaminated excavated soils will be handled in an environmentally safe manner. Options include: 1) landfarming or composting; 2) bio-venting; 3) soil flushing; 4) thermal desorption; 5) interim containment on site pending the design of comprehensive treatment strategies at the conclusion of the RI/FS; and 6) permanent, on-site/off-site containment. Optimal treatment will be determined in part by the extent and magnitude of contaminated soils excavated during construction.



FREE PRODUCT REMOVAL TRENCH CROSS SECTION



CONCRETE EXTRACTION MANHOLE CROSS SECTION

FA213

Fig. 14. Cross section of free-product removal system and detail drawing of concrete extraction manhole. Conceptual detail only; not for construction purposes.

Because of the small volumes of contaminated soils expected to be generated (less than 500 m^3 or 650 yd^3), the site is ideally suited for pilot studies to address the feasibility of these options. A study addressing soil-treatment alternatives and relevant pilot studies is currently being prepared and will be submitted at a later date. In an effort to implement free-product removal in the most expedient manner possible, it is recommended that contaminated soils be contained on-site while this study is being completed. Provisions must, therefore, be made to contain excavated soils at an on-site surface containment facility. The containment facility should have an impermeable base with provisions to control surface-water flow. A section of unused pavement or concrete with appropriate berms and surface-water control would suffice.

After the extraction trench has been excavated, approximately 100 m^3 (133 yd^3) of 3.8-cm-(1.5-in.)diameter washed rock will be placed as backfill. Clean, compacted soil will then be placed over the permeable rock to an elevation level with the surrounding ground surface. Compaction will be sufficient to minimize surface infiltration into the backfill. A 2% mounding will be maintained on surface fill to direct any surface runoff away from the collection system.

Placement of backfill material will include the installation of one 61-cm (24-in.), fully screened extraction well and two 5-cm (2-in.), fully screened monitoring wells. The extraction well should be centrally located in the trench with the two monitoring wells equally spaced on either side of it (Fig. 14). In order to facilitate preliminary design, the length of each extraction trench will not exceed 30 m (98 ft). Nonetheless, an accurate determination of this parameter requires subsurface sampling during installation as described above. If analytical results indicate a larger trench is advisable, additional recovery and monitoring wells should be installed. In such cases, the maximum distance between recovery wells should be maintained at approximately 30 m (98 ft).

As shown in Fig. 14, a concrete manhole is recommended for surface access to the extraction well. This structure will insulate the recovery equipment and well from adverse weather and normal fuel-farm activities. In addition, the sump/hydrocarbon detection system in the bottom of the manhole will ensure that the extraction system does not serve as a conduit for introduction of accidental surface discharges into the underlying aquifer. This is a desirable safety feature because two of the four extraction systems (the oil/water separator leach field and the area northeast of storage tank 204B) are located in low lying areas where potential surface discharges may accumulate. While this same effect may be achieved more economically by simply elevating well casings above ground level, the added durability of the concrete manhole is desirable in light of the time frame of removal operations and the potential future use of the system for two-phase recovery and bioremediation.

Single-phase free-product recovery will be conducted on each of the four extraction trenches. Recovered product will be routed to four 380-L (100-gal) surface storage facilities for subsequent recycling. Monitoring will be conducted to assess the effectiveness of the removal systems. Installation and operation of the system will provide important information concerning site-characterization parameters.

Gradient manipulation of the Lower Diagonal No. 1 Drain is required to establish a positive-pressure head along the north boundary of the facility and establish enhanced product flow to the recovery trenches in the northern portion of the facility. Although regional groundwater flow is southeasterly, localized flow from the northern portion of the facility may discharge into the drain during periods when surface flow is low. Establishing a constant, positive-pressure head will prevent this type of seepage discharge from entering the ditch and contaminating surface flow.

As shown in Fig. 15, alteration of the surface-water flow gradient in the Lower Diagonal No. 1 Drain will be achieved by installing a weir

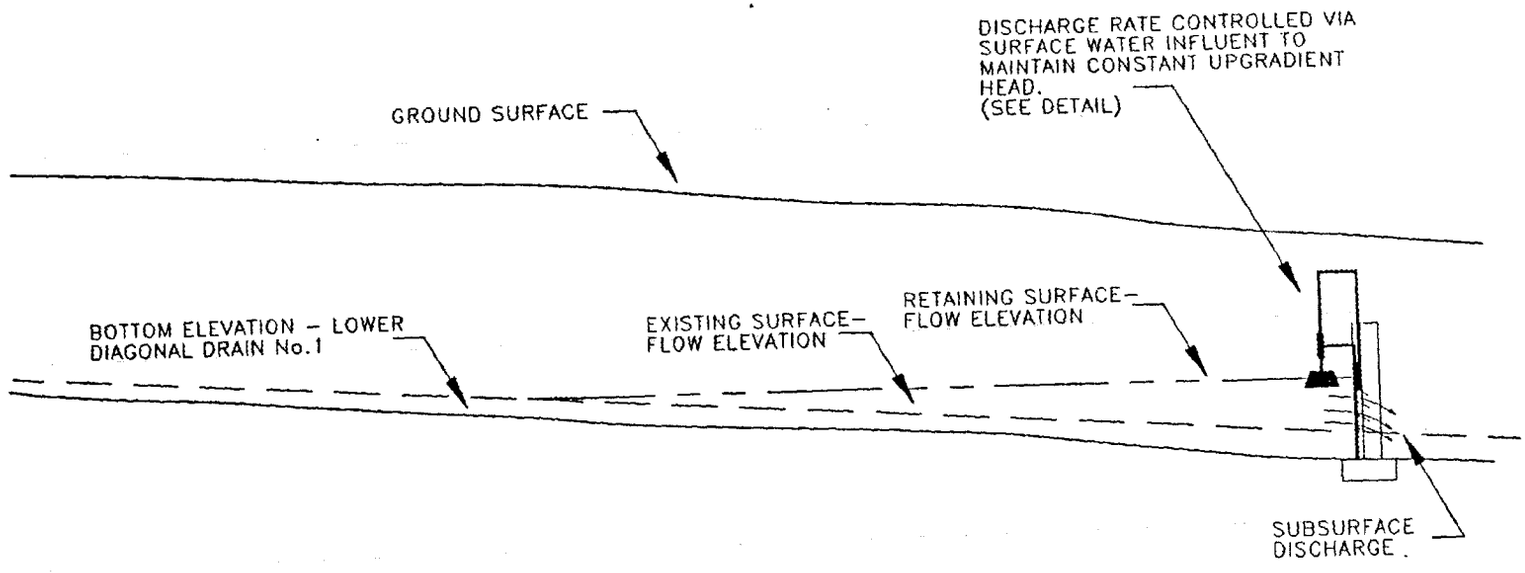


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Fig. 15. Cross section of Lower Diagonal Drain No.1, containment/gradient control system.

in the ditch downgradient from Site 2. The weir system shown in Fig. 16 is designed to balance stream influent and effluent through a metered gate system at the bottom of the drain. In this manner, a constant-head, no-flow zone is established in the upper 15 cm (6 in.) of retained fluid. This feature is desirable to provide a static-head boundary at the north end of the site to minimize residual soils contamination caused from seasonal fluctuations in the water table. The positive head will establish recharge of clean surface water into Site 2 and thus prevent contaminants from seeping into the drainage system. The influx of fresh water will create a groundwater mound inducing contaminant migration towards the downgradient extraction trenches. In an effort to minimize undesirable effects on indigenous flow patterns, it is recommended that the positive head differential established between the potentiometric surface and the surface-water flow elevation be held to a maximum of 15 cm (6 in.) above the seasonally high-flow line. This maximum parameter is easily accomplished through proper design of the weir system (Fig. 16).

As a secondary benefit, the stagnant flow zone established on the surface of retained fluid allows efficient monitoring and removal of any free petroleum product which may be accidently introduced into the ditch. If floating product is discovered, the weir can be closed, and a skimmer system may be employed for direct removal of contaminants from the drainage ditch. Alternatively, the weir is designed with sufficient freeboard to allow for 24-hour storage capacity in the drainage ditch [1.66-m (5.4-ft) depth before spillway overflow] if the weir is closed to prevent discharge of contaminated effluent. This time interval is then available for using a portable treatment system to remediate the retained contaminants.

CONCLUSIONS AND RECOMMENDATIONS

Previous site characterization and existing analytical results support the following conclusions and recommendations:

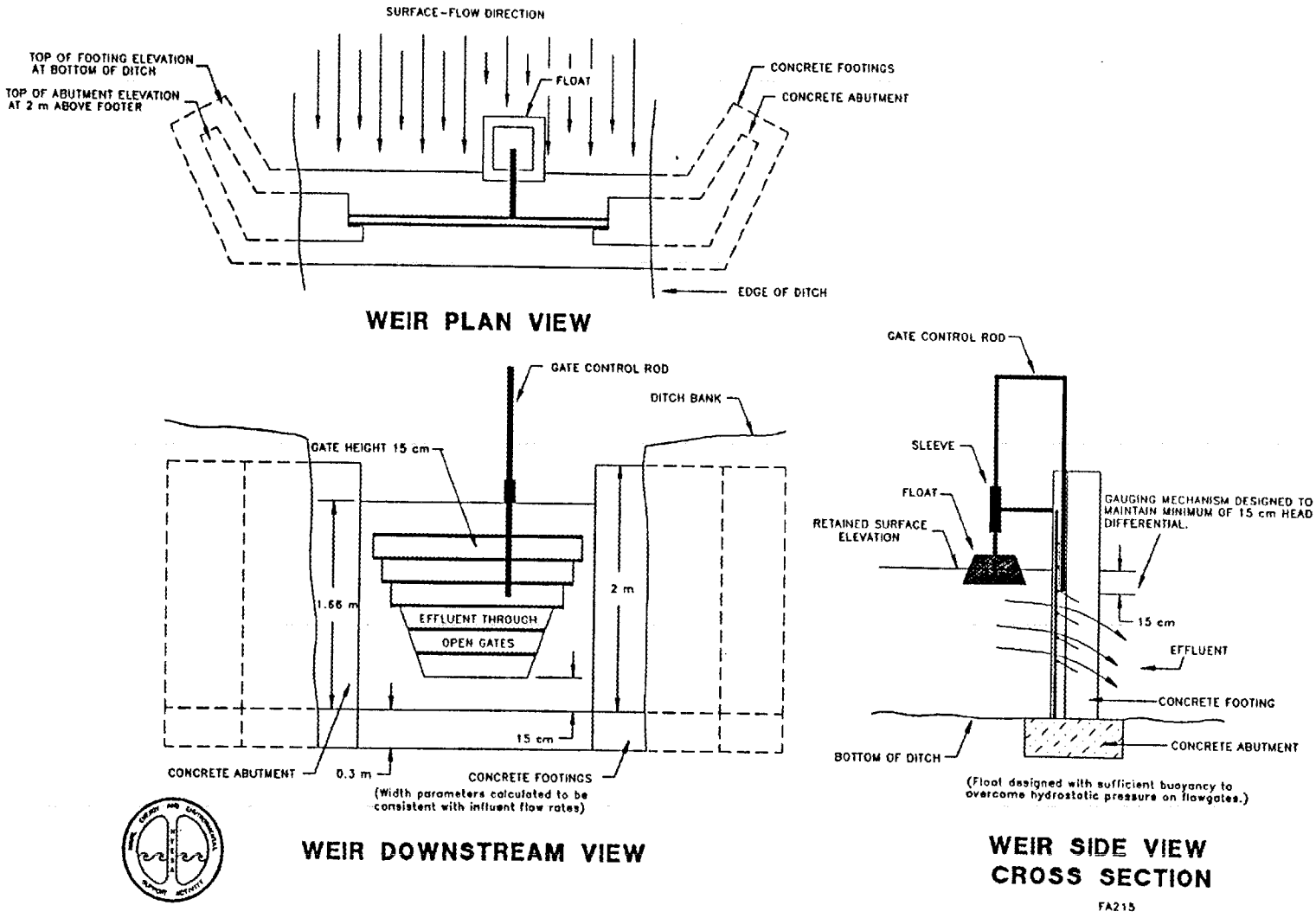

Fig. 16. Detail of Lower Diagonal Drain No. 1 weir. Conceptual detail only; not for construction purposes.

CONCLUSIONS

1. Wide-spread petroleum hydrocarbon contaminants related primarily to JP-5 are present in the shallow subsurface at Site 2. Although zones of high hydraulic conductivity underlie the facility, existing contaminants appear to be relatively immobile. Analytical results indicate that contaminants are either held at residual saturation in the shallow subsoils or contained as free product floating on the underlying water table.

2. Site-characterization data is sufficient to implement free-product removal actions complying with NDEP legal actions.

3. Site-characterization information is not sufficient to develop and screen remedial alternatives for contaminants of concern at Site 2. While the range of contaminant concentrations present in the groundwater is apparent, the extent of subsoil residual contamination requires further definition.

RECOMMENDATIONS

1. Recommended free-product removal actions include: 1) a free-product removal plan incorporating four extraction trenches and a single recovery floating skimmer pump in each trench, and 2) manipulation of the flow gradient in the Lower Diagonal No.1 Drain to establish a groundwater mound and provide enhanced free-product recovery in the downgradient trenches.

2. It is recommended that a subsurface sampling program be initiated during implementation of the free-product removal actions to address the need for additional site-characterization data discussed above. Sampling activities should consist of collecting at least one

soil sample and one groundwater sample (where present) at 30-cm (1-ft) intervals as excavation progresses in each trench. Samples will be field screened with a gas chromatograph for petroleum hydrocarbons. One soil and one groundwater sample from each trench will be sent for laboratory analysis to verify field-screening results. Samples will be analyzed for VOC (method 624) and TPH (method 8015 modified). It is requested that ORNL/GJ personnel be notified when work is initiated on the free-product removal system. Field-sampling personnel may thus be present during excavation to obtain samples of the exposed subsurface. It is further recommended that the resulting information be reviewed and used to design additional Phase II sampling activities necessary for the development and screening of remedial alternatives.

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ACRONYMS AND ABBREVIATIONS

ARARs	--	Applicable or Relevant and Appropriate Requirements
ASTM	--	American Society for Testing and Materials
av-gas	--	aviation gasoline
BNA	--	base/neutral, acid extractable semivolatile organics
CERCLA	--	Comprehensive Environmental Response, Compensation, and Liability Act
cm^2/s	--	square centimeters per second
Comp.	--	composite
DEP	--	Division of Environmental Protection (Nevada)
DOD	--	Department of Defense
EM	--	electromagnetometer
EPA	--	Environmental Protection Agency (United States)
ft^2/day	--	square feet per day
gal	--	gallons
gal/day/ft	--	gallons per day per foot
$gal/day/ft^2$	--	gallons per day per square foot
GC	--	gas chromatograph
IR Program	--	Installation Restoration Program
MCLs	--	maximum contaminant levels
m	--	meters
$\mu g/kg$	--	microgram per kilogram
$\mu g/L$	--	microgram per liter
mg/kg	--	milligram per kilogram
mg/L	--	milligram per liter
mL	--	milliliter
mogas	--	motor vehicle gasoline
NAAS	--	Naval Air Auxiliary Station
NAS	--	Naval Air Station

ND	--	not detected
NDEP	--	Nevada Division of Environmental Protection
NEESA	--	Naval Energy and Environmental Support Activity
NPDES	--	National Pollutant Discharge Elimination System
NRS	--	Nevada Regulatory Statutes
ORNL/GJ	--	Oak Ridge National Laboratory - Grand Junction
OVA	--	organic vapor analyzer
PA/SI	--	Preliminary Assessment/Site Inspection
PID	--	photoionization detector
POTW	--	Publicly Owned Treatment Works
ppm	--	parts per million
RI/FS	--	Remedial Investigation/Feasibility Study
RMCLs	--	recommended maximum contaminant levels
SARA	--	Superfund Amendments and Reauthorization Act
TDS	--	total dissolved solids
TIC	--	tentatively identified compound
TPH	--	total petroleum hydrocarbons
USRADS	--	ultrasonic ranging and data collection system
VOC	--	volatile organic compounds

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