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CONTAMINATION ASSESSMENT REPORT REMEDIAL ACTION PLAN FOR THE DEFENSE
FUEL SUPPLY POINT CNC CHARLESTON SC
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KEMRON ENVIRONMENTAL SERVICES, INC

CONTAMINATION ASSESSMENT REPORT - REMEDIAL ACTION PLAN
FOR THE DEFENSE FUEL SUPPLY POINT
CHARLESTON NAVAL ~~STATION~~ base
CHARLESTON, SOUTH CAROLINA
UIC: M60169

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The Preliminary Contamination Assessment Study team thanks the many people at the Naval Supply Center, Naval Petroleum Office, and the Southern Division Naval Facilities Engineering Command, who cooperated to make successful completion of this study possible. We would also like to gratefully acknowledge the efforts and assistance of the Naval Energy and Environmental Support Activity.

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EXECUTIVE SUMMARY

This document is a contamination assessment report (CAR) and a remedial action plan (RAP). As a contamination assessment report, it reports the recent completion of delineation work at the Defense Fuel Supply Point (DFSP), Naval Supply Center, Naval ~~Shipyard~~^{BASE}, Charleston, South Carolina. It also reports the findings, in summary, of prior studies, describes the fate and transport of contaminants, and describes risks which the site may pose. As a remedial action plan, it discusses what must be accomplished during remediation in order to protect human health and the environment and what must be accomplished to meet relevant and applicable clean-up criteria. Possible ways to meet these remediation goals are discussed. These various methods are evaluated for effectiveness, implementability and cost. Finally, a preferred alternative is recommended.

DFSP is an old but active above ground tank farm for fuels and waste oils at the Naval Shipyard approximately 400 yards southwest of the Cooper River. It covers about 35 acres and once had a capacity of approximately 275,000 barrels (11.55 million gallons) spread over eight tanks. Its capacity is now only 147,500 barrels due to the closure and demolition of three obsolete tanks. Soils and shallow groundwaters at the site are moderately to severely contaminated with fuels in two areas from which leaking tanks were removed.

The risk to human health and the environment from this site is negligible. However, two areas at the site exceed applicable criteria.

Soils at the site could be excavated or could be treated in place. If excavated, soils could be transported to a treatment or disposal facility, or could be treated onsite. Onsite ex situ

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treatment could use either thermal or biological methods. If treated in place, a biological method would be used. Contaminated shallow groundwaters may be adequately treated as a concomitant of soil treatment or may need separate methods. If separate methods are necessary, discharge without treatment to the Charleston POTW is proposed.

Evaluation of the alternatives reveals that in situ treatment using a modified landfarming technique will be most cost-effective. Nutrient deficits will be corrected by adding fertilizer to the soil and the vadose zone will be aerated using a deep-till harrowing technique. Native microorganisms, having already begun to break down the wastes, will be stimulated to complete constituent degradation.

TABLE OF CONTENTS

30-Dec-1993 04:50:54am

	<u>Page</u>
ACKNOWLEDGEMENTS	
EXECUTIVE SUMMARY	
LIST OF TABLES	iii
LIST OF FIGURES	iv
1. INTRODUCTION	1-1
1.1 PURPOSE AND SCOPE	1-1
1.2 SITE DESCRIPTION	1-1
1.3 SITE HISTORY AND REGULATORY STATUS	1-3
1.4 REPORT ORGANIZATION	1-3
2. SITE CHARACTERIZATION	2-1
2.1 PRIOR STUDIES	2-1
2.1.1 Scope	2-1
2.1.2 Results	2-3
2.1.3 Conclusions	2-3
2.2 RECENT STUDIES	2-5
2.2.1 Purpose	2-5
2.2.2 Soil Sampling	2-6
2.2.3 Groundwater Sampling	2-9
2.3 CHARACTERISTICS OF STUDY AREA	2-12
2.3.1 Topography and Physiography	2-12
2.3.2 Climatology	2-12
2.3.3 Surface Hydrology	2-14
2.3.4 Regional Geology	2-15
2.3.5 Soils	2-15
2.3.6 Hydrogeology	2-15
2.3.7 Demography and Land Use	2-18
2.3.8 Ecology	2-19
2.4 NATURE AND EXTENT OF CONTAMINATION	2-19
2.4.1 Composition	2-19
2.4.2 Sources	2-20
2.4.3 Extent in Soils	2-20
2.4.4 Extent in Groundwater	2-25
2.4.5 Surface Water and Sediments	2-27
2.4.6 Air	2-27
2.5 CONTAMINATION FATE AND TRANSPORT	2-27
2.5.1 Transport Mechanisms	2-27
2.5.2 Attenuation Mechanisms	2-32
2.5.3 Plume History	2-35
2.5.4 Plume Fate	2-37
2.6 RISK ASSESSMENT	2-37
2.6.1 Human Health	2-38
2.6.2 Environment	2-39

TABLE OF CONTENTS (continued)

	<u>Page</u>
3. DEVELOPMENT AND SCREENING OF ALTERNATIVES	3-1
3.1 REMEDIAL OBJECTIVES	3-1
3.1.1 Protection of Human Health	3-1
3.1.2 Protection of the Environment	3-2
3.1.3 Applicable and Relevant Criteria	3-2
3.2 ALTERNATIVES	3-3
3.2.1 Ex Situ Alternatives	3-4
3.2.1.1 Groundwater Treatment and Disposal	3-4
3.2.1.2 Landfilling	3-6
3.2.1.3 Thermal Treatment	3-6
3.2.1.4 Biological Treatment	3-7
3.2.2 In Situ Alternatives	3-8
3.2.2.1 No Action	3-8
3.2.2.2 Landfarming/Biostimulation	3-8
3.2.2.3 Subsurface Biotreatment	3-13
3.3 EVALUATION OF ALTERNATIVES	3-13
3.3.1 Effectiveness and Implementability	3-14
3.3.2 Cost	3-15
3.3.3 Recommended Alternative	3-19
3.3.4 Recommended Monitoring and Sampling	3-24
4. REFERENCES	4-1
5. BIBLIOGRAPHY	5-1
APPENDIX A - ESE Laboratory Results	
APPENDIX B - Boring Logs	
APPENDIX C - KEMRON Laboratory Results	
APPENDIX D - Factors Affecting biodegradation Rates	

LIST OF TABLES

		<u>Page</u>
2-1.	Intervals of soil sample retrieval and laboratory results	2-10
2-2.	Summary of groundwater analysis	2-11
3-1.	Summary cost matrix	3-18
3-2.	Summary evaluation matrix	3-20

30-Dec-1993 04:50:59am

LIST OF FIGURES

	<u>Page</u>
1-1. Plan view, Defense Fuel Supply Point	1-2
2-1. Monitoring well and surface water/shallow sediment sampling locations	2-2
2-1a. TPH concentrations and approximate areas of visual/olfactory evidence of petroleum contamination	2-4
2-2. Borehole location map	2-7
2-3. Vicinity map	2-13
2-4. Regional geologic cross-section (NW-SE)	2-16
2-5. Regional geologic cross-section (SW-NE)	2-17
2-6. Estimated intervals of soil contamination (1986/87-1990)	2-22
2-7. Cross section location map	2-23
2-7a. Estimated vertical extent of petroleum contaminated soils	2-24
2-8. Gravitational transport of petroleum release	2-29
2-9. Transformation of mobile hydrocarbon into residual saturation ...	2-33
3-1. Defense Fuel Supply Point Contingency Trenches	3-22
3-2. Proposed monitoring well locations	3-27
3-3. Proposed monitoring well schematic	3-29

CHAPTER 1. INTRODUCTION

This chapter provides materials which place the remainder of the document in context.

1.1 PURPOSE AND SCOPE. This document is a contamination assessment report (CAR) and remedial action plan (RAP) for the Defense Fuel Supply Point (DFSP), an above ground petroleum tank farm, operated by the Naval Supply Center, at the Charleston (South Carolina) Naval ~~Shipyard~~^{BASE}. As a CAR, this document reports the recent completion of the contamination assessment at DFSP. It also summarizes prior studies and provides data on what is likely to become of the contamination found and what risks this poses. As a RAP, this document discusses contaminant concentrations (remediation goals) which must be achieved to protect human health and the environment and to satisfy requirements of the South Carolina Department of Health and Environmental Control (DHEC). It considers various ways in which these remediation goals could be achieved and recommends a preferred method. The overall purpose of this document is to provide the conceptual basis for site remediation plans.

This document was prepared by Kemron Environmental Services, Inc., Southeastern Regional Office, at the request of the Department of the Navy, Southern Division, Naval Facilities Engineering Command (E. R. Batten, Engineer in Charge) under contract number N62467-87-D-0650.

1.2 SITE DESCRIPTION. DFSP is one of two fuel and lubricant tank farms serving the Naval Shipyard. The other is the Chicora Tank Farm located about half a mile to the southwest. Figure 1-1 is a plan view of DFSP. The location of DFSP within the Naval Shipyard and the

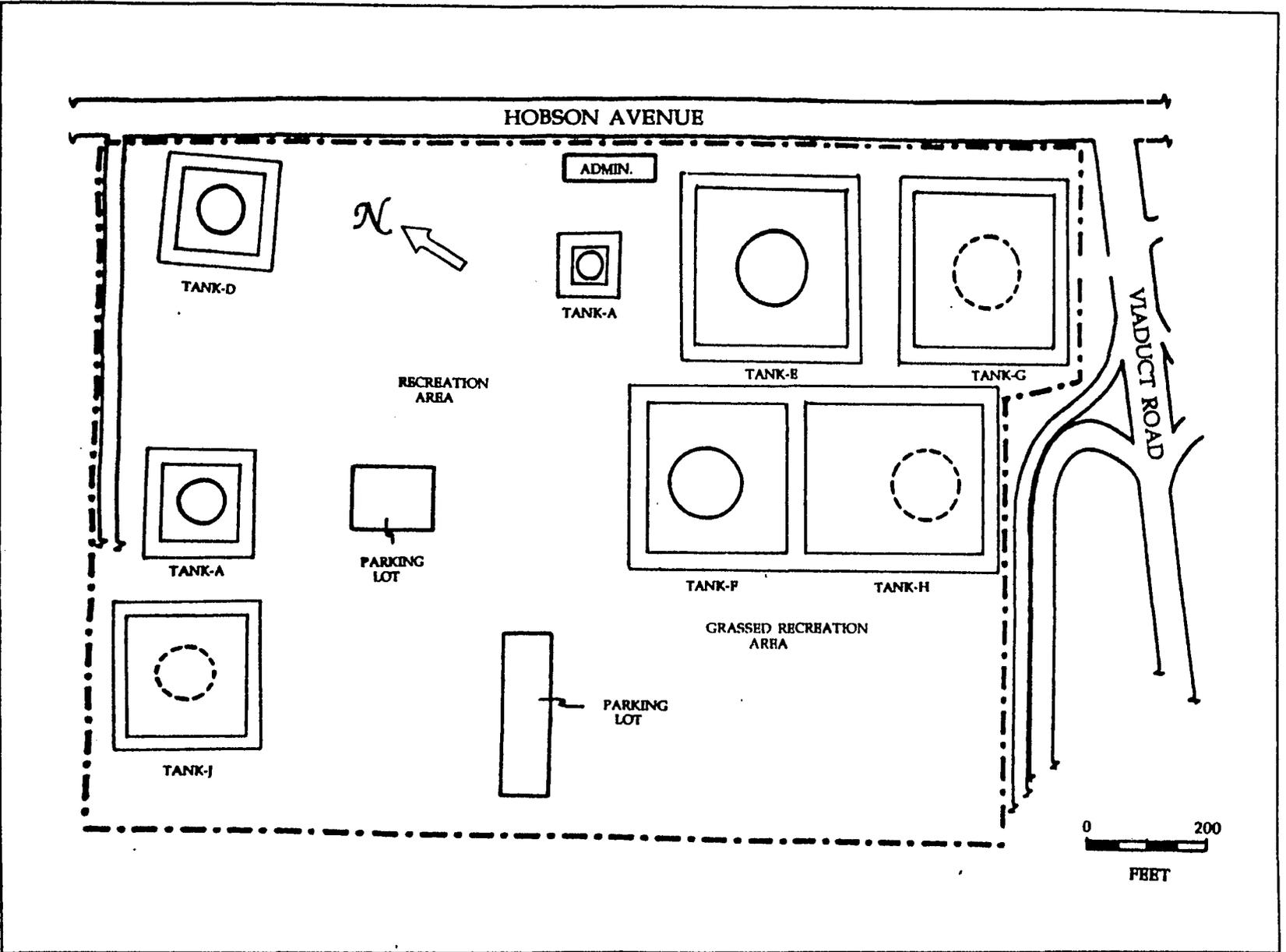


Figure 1-1. Plan view, Defense Fuel Supply Point.

location of the Shipyard in Charleston are described in paragraph 2.3.1. The site is flat, low lying ground except for the berms around the tanks. At one time there were eight tanks: four 55,000 bbl tanks, three 17,500 bbl tanks and one 2,500 bbl tank. The four larger tanks were concrete, the remaining tanks were steel. Two of the concrete tanks and one of the 17,500 bbl steel tanks have been dismantled. The two large tanks remaining in service are used for the storage of diesel fuel, the smaller tanks are used for waste oil.

1.3 SITE HISTORY AND REGULATORY STATUS. The site was first used for fuel and lubricant storage in the early 1900's with construction of two 17,500 bbl tanks which are still in use. All other tanks at the site were constructed between 1936 and 1944. The dismantled steel tank developed a leak in 1955 and was taken out of service at that time. A liner was installed in the tank in 1979 but it continued to leak and could not be used. It was finally demolished in February 1986. The two concrete tanks that have been taken down were demolished at the same time. They had been found to leak in 1974 when they were switched from storing Navy Special Fuel Oil to the less viscous Navy Distillate. Diesel fuel storage was attempted in 1975, failed, and the concrete tanks were taken out of service until their demolition in 1986.

1.4 REPORT ORGANIZATION. The CAR is Chapter 2 of this document and the RAP is Chapter 3.

CHAPTER 2. SITE CHARACTERIZATION

2.1 PRIOR STUDIES.

2.1.1 Scope The initial site characterization study was performed by Environmental Science and Engineering, Inc., (ESE). ESE examined and sampled shallow soils and groundwaters at the site and nearby surface waters and sediments.

Seven permanent monitoring wells were installed and developed during the period 28-30 July 1986. Samples were collected from the wells on 11 August 1986 and again during the period 18-19 May 1987. The samples collected on 11 August were assayed for total petroleum hydrocarbons (TPH), and benzene, toluene, ethylbenzene, and xylenes (BTEX). The samples collected 18-19 May were analyzed for TPH, BTEX, and polynuclear aromatic hydrocarbons (PAH).

Forty-three soil borings were installed during the period 29-31 July 1986. Borings were advanced to a typical depth of three feet and a maximum depth of 6.5 feet using a two man power auger. Visual and olfactory observations of the borings were recorded. Sampling depths were not reported. Samples were assayed for TPH and BTEX.

Three surface water and three shallow sediment samples were collected from a drainage ditch adjacent to tank J (Figure 2-1). All were assayed for TPH and BTEX.

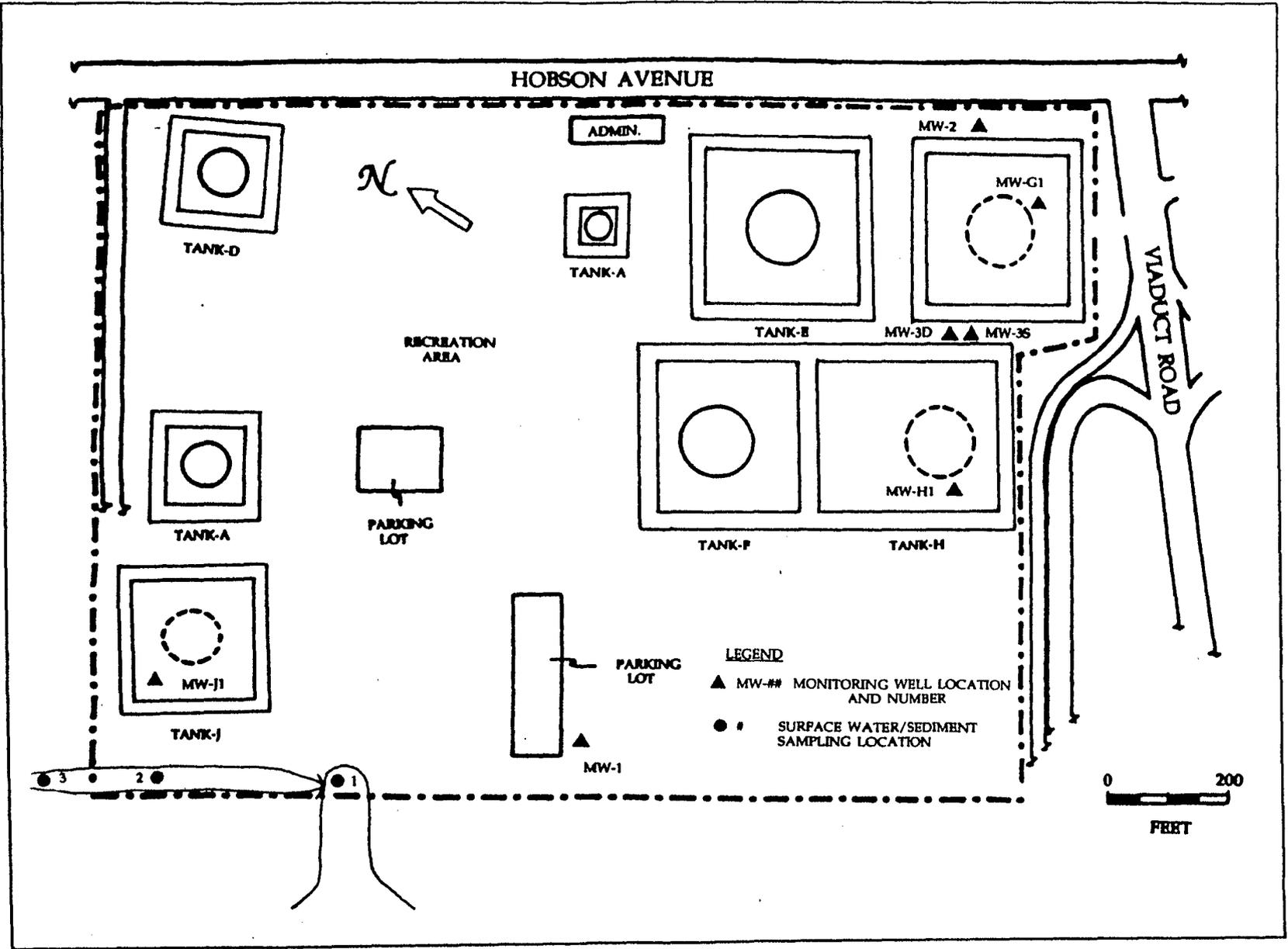


Figure 2-1. Monitoring well and surface water/shallow sediment sampling locations.

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2.1.2 Results Groundwater samples collected on 11 August 1986 from monitoring wells 3S, G1, and H1 (Figure 2-1) contained high (>100 ppm) TPH concentrations. Benzene was only detected in one well, 3S at 1.23 µg/l. Contaminant concentrations were lower in samples retrieved 18-19 May 1987. TPH concentrations above detectable limits were only found in wells 3S and 3D (Figure 2-1). BTEX was not detected at all.

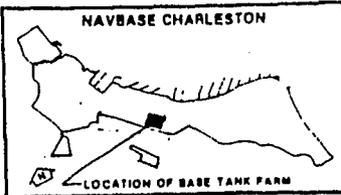
PAH compounds were found in groundwater samples retrieved 18-19 May from each of the seven wells. However, only four wells (2, 3D, 3S, and G1) had concentrations greater than World Health Organization (WHO) drinking water limits. The highest concentrations were detected in samples from wells 3D and 3S.

Laboratory results of soil samples collected 29-31 July 1986 showed TPH concentrations ranging from none detected to 9010 mg/kg. No BTEX was found. Visual and olfactory observations of soils confirmed the TPH results but found a somewhat larger area of contamination.

Neither TPH nor BTEX was found in surface water samples collected from the ditch adjacent to tank J. In sediments, from the drainage ditch, TPH ranged from 43.9 ppm to 268.0 ppm. No sediment BTEX was found.

Laboratory results of ESE's soil, groundwater, surface water, and surface sediment samples are included in Appendix A.

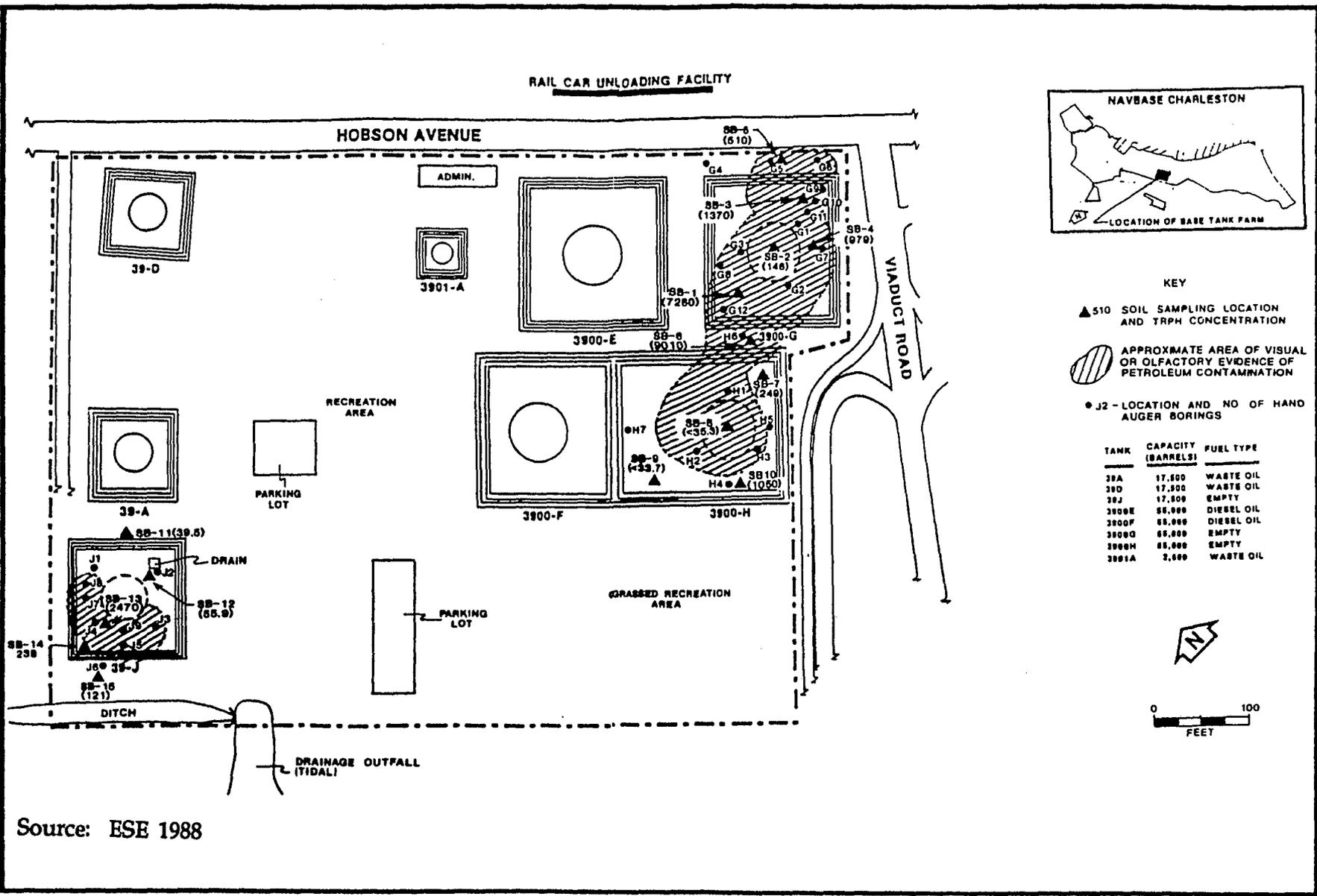
2.1.3 Conclusions ESE found two areas of contamination. The larger area, surrounding pads G and H (Figure 2-1a), was reported to cover an area of 49,800 ft² centered around wells 3D and



KEY

- ▲ 510 SOIL SAMPLING LOCATION AND TRPH CONCENTRATION
- ◌ APPROXIMATE AREA OF VISUAL OR OLFACTORY EVIDENCE OF PETROLEUM CONTAMINATION
- J2 - LOCATION AND NO OF HAND AUGER BORINGS

TANK	CAPACITY (BARRELS)	FUEL TYPE
39A	17,500	WASTE OIL
39D	17,500	WASTE OIL
39J	17,500	EMPTY
3900E	55,000	DIESEL OIL
3900F	55,000	DIESEL OIL
3900G	55,000	EMPTY
3900H	55,000	EMPTY
3901A	2,000	WASTE OIL



Source: ESE 1988

Figure 2-1a. TPH concentrations and approximate areas of visual/olfactory evidence of petroleum contamination (ESE, 1988).

3S. It was found to extend to a depth of eight feet. Hence, the larger area was reported to comprise 15,000 yd³. The smaller area, centered around well J-1, was reported to cover 6,000 ft² and extend to a depth of four feet. Hence, the smaller area was reported to comprise 900 yd³.

An error in the scaling factor used to calculate contaminated areas compromised the above calculations. The scaling factor was off by approximately 13/7. Hence, the original and recomputed areas and volumes contaminated should have been reported as follows:

<u>Contaminated Area</u>	<u>Area (ft²)</u>		<u>Volume (yd³)</u>	
	<u>Original</u>	<u>Recomputed</u>	<u>Original</u>	<u>Recomputed</u>
The Larger Area	49,800	172,000	15,000	50,900
The Smaller Area	6,000	20,700	900	3,100

Although contamination was found to impact a significant proportion of the site, off-site contamination appeared to be insignificant.

2.2 RECENT STUDIES.

2.2.1 Purpose Review of the initial site assessment study by DHEC produced suggestions that additional data be gathered from area soils regarding the vertical distribution of contamination. It was also suggested that the wells be resampled due to the time lapse since the prior study. KEMRON performed this work at the request of SOUTHDIV.

All soil and groundwater samples collected during KEMRON's investigation were collected using EPA procedures, placed in appropriate pre-labeled containers, cooled to 4°C, and shipped

to the laboratory via overnight courier. Chain-of-custody procedures were documented from the field to the laboratory.

2.2.2 Soil Sampling Nine soil borings were installed in areas found to be contaminated during the 1986-87 characterization study. The borings were installed using a 2-inch O.D. stainless steel hand auger to depths ranging from six to ten feet below ground surface. Boring locations are shown on Figure 2-2. Locations were chosen to represent a range of conditions from highly to marginally contaminated.

The sampling plan called for collection of samples every two feet in each boring. However, in some borings, liquefaction was so pronounced several feet below the water table, that deep samples could not be attributed to the planned intervals and were composited. Soil samples were retrieved at two foot vertical intervals to a total depth of ten feet in boreholes #1, 3, 5, and 7. Soil samples were retrieved from two foot vertical intervals to a total depth of six feet in boreholes #6, 8, and 9. A single composite soil sample was subsequently retrieved from each of boreholes #6, 8, and 10 from depths of eight to ten feet. Soil samples were retrieved from two foot vertical intervals to total depths of six feet in borehole #2 and eight feet in borehole #4. All of the above mentioned samples were assayed for TPH. Soil samples retrieved from borehole #6 at a depth of five feet, borehole #7 at a depth of eight feet, and borehole #9 at a depth of two feet were assayed for PAH.

The soils retrieved from each borehole were monitored in the field with a photo-ionization detector (PID) for indications of organic vapors to assist in determining the extent of petroleum contamination beneath the site. Organic vapors in site soils are virtually undetectable. Soils

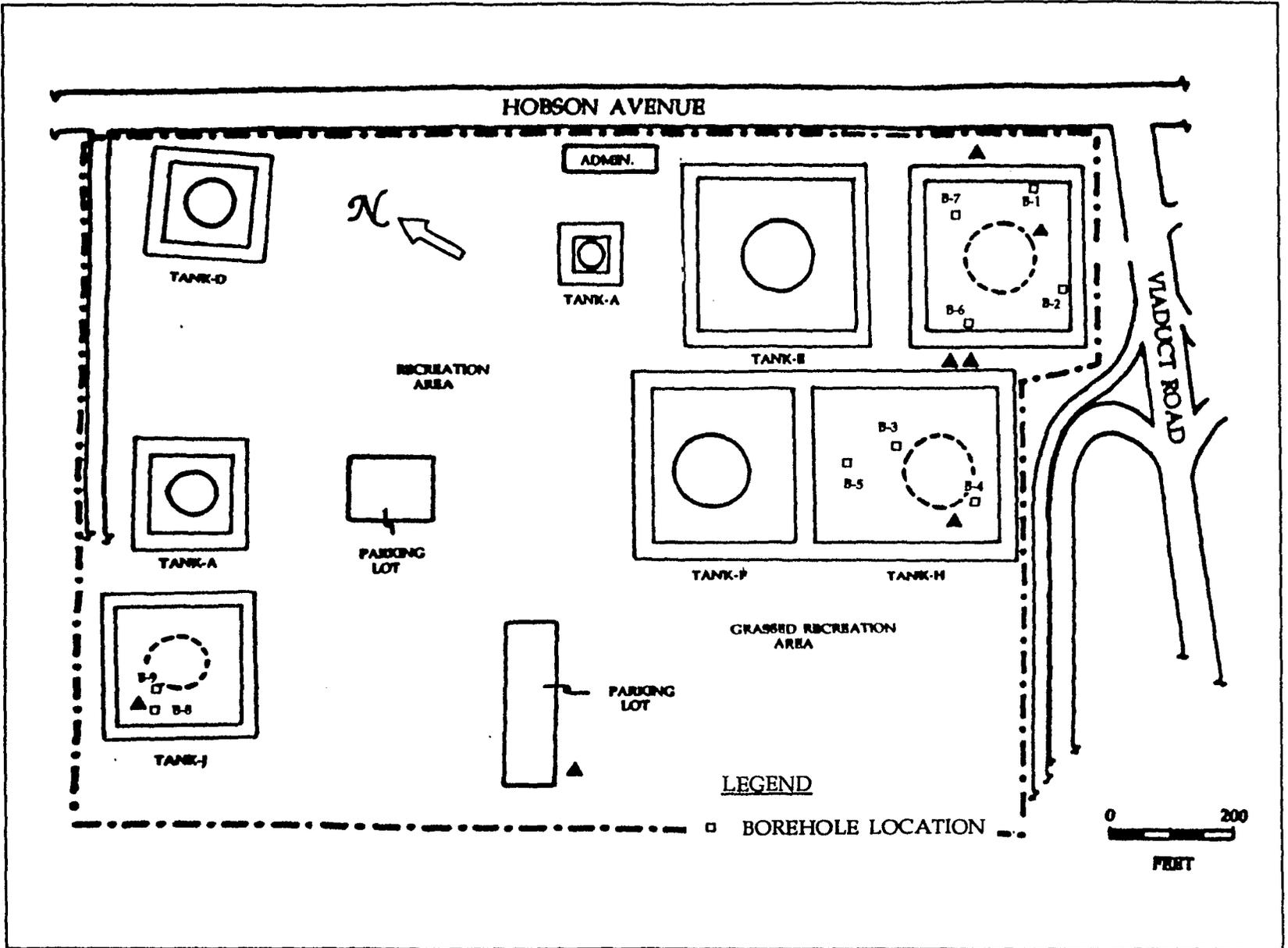


Figure 2-2. Borehole location map.

from each borehole, on removal from the hand auger, were inspected for soil characteristics which were recorded on borehole specific logs. Logs are included in Appendix B.

The Vicinity of Former Tank G

TPH was only detected in samples retrieved from boreholes #6 and #7. Boreholes #6 and #7 are located within the bermed area surrounding former tank G. Borehole #6 contained TPH concentrations of: 26 ppm at a depth of two feet, 3,500 ppm at a depth of four feet, and 70 ppm at a depth of eight to ten feet. No TPH was found at six feet. The PAH assay conducted on soil from five feet below grade in borehole #6 found (only) phenanthrene at 50 µg/kg. Borehole #7 contained TPH at 32 mg/kg two feet below grade and 43 mg/kg six feet below grade. No TPH was found at depths of four, eight, or ten feet. The PAH assay, conducted on a sample from a depth of eight feet in borehole #7 found nothing. No TPH was found in borehole #1 or #2; like #6 and #7, both were located within the bermed area surrounding former tank G.

The Vicinity of Former Tank H

No TPH was detected in samples retrieved from boreholes #3, 4, or 5. These boreholes were all located within the bermed area surrounding former tank H.

The Vicinity of Former Tank J

No TPH was detected in borehole #8, located inside the bermed area surrounding former tank J. A TPH concentration of 320 mg/kg was detected in the two foot sample from borehole #9,

also located inside the bermed area surrounding former tank J. No TPH was found in the other samples from borehole #9. However, the PAH assay conducted on a soil sample retrieved from a depth of two feet in borehole #9 found two compounds, acenaphthylene at 155 $\mu\text{g}/\text{kg}$ and fluoranthene at 97 $\mu\text{g}/\text{kg}$. Laboratory results of soil samples retrieved from consecutive intervals in boreholes #1 through #9 are presented in Table 2-1 and in Appendix C.

2.2.3 Groundwater Sampling All seven on-site monitoring wells were sampled on 26 February 1990. Each monitoring well was purged of three well volumes prior to sampling. Dedicated PVC bailers were used to retrieve groundwater samples from each of the seven on-site monitoring wells. The samples retrieved from each monitoring well were assayed for TPH and PAH. An additional groundwater sample retrieved from monitoring well 3S was assayed for BTEX.

Measurable TPH was found only in MW-2 (at 1.4 ppm). No BTEX was found. PAH compounds were found only in MW-G1 and MW-3S. MW-G1 contained fluorene at 2 $\mu\text{g}/\text{l}$ and pyrene at 3 $\mu\text{g}/\text{l}$. MW-3S contained 9 $\mu\text{g}/\text{l}$ acenaphthene, 5 $\mu\text{g}/\text{l}$ fluorene, 8 $\mu\text{g}/\text{l}$ phenanthrene, 2 $\mu\text{g}/\text{l}$ anthracene, 14 $\mu\text{g}/\text{l}$ fluoranthene, 15 $\mu\text{g}/\text{l}$ pyrene, 2 $\mu\text{g}/\text{l}$ benzo(a)anthracene, and 2 $\mu\text{g}/\text{l}$ chrysene.

The reported concentrations of the last two compounds listed above are below the nominal method detection limit. Laboratory results for groundwater samples retrieved from the seven on-site monitoring wells are presented in Table 2-2 and in Appendix C.

Table 2-1. Intervals of Soils Sample Retrieval and Laboratory Results.

Borehole	Depth	TPH Result (mg/kg)	Borehole	Depth(ft)	TPH Result (mg/kg)
B-1	2	BDL	B-6	2	26
	4	BDL		4	3500
	6	BDL		5	*
	8	BDL		6	BDL
	10	BDL		8/10	70
B-2	2	BDL	B-7	2	32
	4	BDL		4	BDL
	6	BDL		6	43
				8	BDL**
B-3	2	BDL	B-8	10	BDL
	4	BDL		2	BDL
	6	BDL		4	BDL
	8	BDL		6	BDL
	10	BDL		8/10	BDL
B-4	2	BDL	B-9	2	320***
	4	BDL		4	BDL
	6	BDL		6	BDL
	8	BDL		8/10	BDL
B-5	2	BDL			
	4	BDL			
	6	BDL			
	8	BDL			
	10	BDL			

BDL = Below Detection Limit

* = PAH Assay Result: 50 µg/kg Phenanthrene

** = PAH Assay Result: BDL

*** = PAH Assay Result: 155 µg/kg Acenaphthylene, 97 µg/kg Fluoranthene

All soil sample data obtained during sampling event of 17-18 January 1990.

Table 2-2. Summary of Groundwater Analysis.

Monitoring Well #	Parameter	Laboratory Results
2	TPH PAH	1.4 mg/l BDL
G-1	TPH PAH	BDL 2 µg/l Fluoranthene 3 µg/l Pyrene
3S	TPH BTEX PAH	BDL BDL 9 µg/l Acenaphthene 5 µg/l Fluorene 8 µg/l Penanthrene 2 µg/l Anthracene 14 µg/l Fluoranthene 15 µg/l Pyrene *2 µg/l Benzo(a)anthracene *2 µg/l Chrysene
3D	TPH PAH	BDL BDL
H1	TPH PAH	BDL BDL
1	TPH PAH	BDL BDL
J1	TPH PAH	BDL BDL

TPH = Total Petroleum Hydrocarbons
 PAH = Polynuclear Aromatic Hydrocarbons
 BTEX= Benzene, Toluene, Ethylbenzene, Xylene
 * = Below Nominal Method Detection Limit

2.3 CHARACTERISTICS OF STUDY AREA.

2.3.1 Topography and Physiography The Charleston Naval Shipyard is located on the eastern edge of a low, narrow peninsula separating the Ashley and Cooper Rivers. Topography (Figure 2-3) in the area is typical of South Carolina's lower coastal plain, having low relief plains broken only by the meandering courses of sluggish streams and rivers which flow toward the coast past occasional marine terrace escarpments. Topography is essentially flat. Elevations range from approximately 20 feet above mean sea level (MSL) in the northwest part of the base, to sea level at the Cooper River. Most of the original topography of the naval base has been modified by man's activities. The southern end of the base was originally tidal marsh drained by Shipyard Creek and its tributaries. The land surface has been filled with both solid wastes and dredged spoil (primarily the latter) over the past 70 years. Most of the base is within the 100-year flood zone (<10 feet MSL).

2.3.2 Climatology The climate of Charleston, South Carolina is mild and temperate due to its latitude and the proximity of the ocean. Daily weather is controlled largely by the movement of pressure systems across and the country and by the diurnal effects of the land-sea breeze. Exchanges of air masses are relatively few in summer, when masses of warm, humid, maritime-tropical (mT) air persist for long periods under Bermuda high pressure conditions. Winters are characterized by movements of frontal systems and by replacement of mT air with cool, dry, continental-polar (cP) air.

The coldest month of the year in Charleston is January, when daily temperatures typically range from approximately 37°F to 60°F. Peak daily temperature during July, the warmest

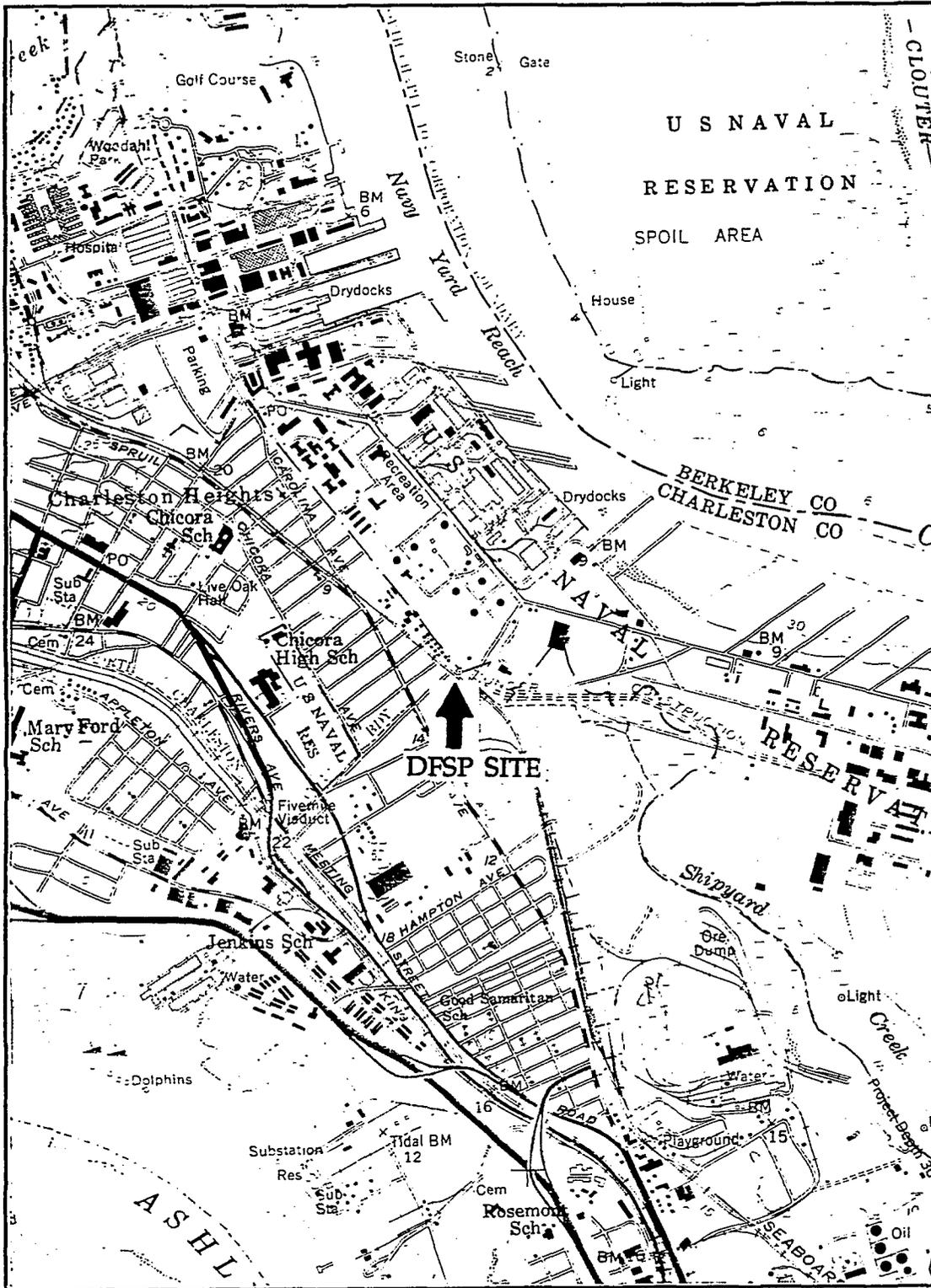


Figure 2-3. Vicinity Map

month of the year, usually varies between approximately 72°F and 90°F. Normally, 60 days per year temperatures reach 90°F or above, while 33 days per year are below freezing. Average annual rainfall in Charleston is 49.2 inches, with a summer peak of more than 7.5 inches occurring in July. The four summer months (June through September) experience more than 50 percent of the annual rainfall (ESE 1988).

2.3.3 Surface Hydrology The southeastern portion of the shipyard is drained by Shipyard Creek. The northern extremes of the base are drained by Noisette Creek. Both creeks are tributaries of the Cooper River. Surface drainage over the remainder of the base flows directly into the Cooper River which flows in a southerly direction and discharges into Charleston Harbor. Shipyard Creek is a small tidal tributary, approximately 1.5 miles in length, which flows in a southeasterly direction along the southwestern base boundary into the Cooper River. Noisette Creek, which transects the northern portion of the base, is a tidal tributary approximately 2.5 miles long. The creek flows nearly due east from its headwaters in the City of North Charleston and empties into the Cooper River.

Runoff from DFSP is collected southwest of the tank farm and flows in a ditch to the northeast, entering a marsh south of tank J. The ditch is wide and shallow southwest of the site. It narrows substantially while becoming deeper in a northeast direction. Flow continues underground through a conduit (approximately 2,500 feet) to the northeast, eventually connecting with the Cooper River. All of these waters are tidally influenced. During the onrush of the tide, surface water flows to the southwest in the ditch. During ebb tide, surface water in the ditch flows to the northeast, in the direction of the Cooper River.

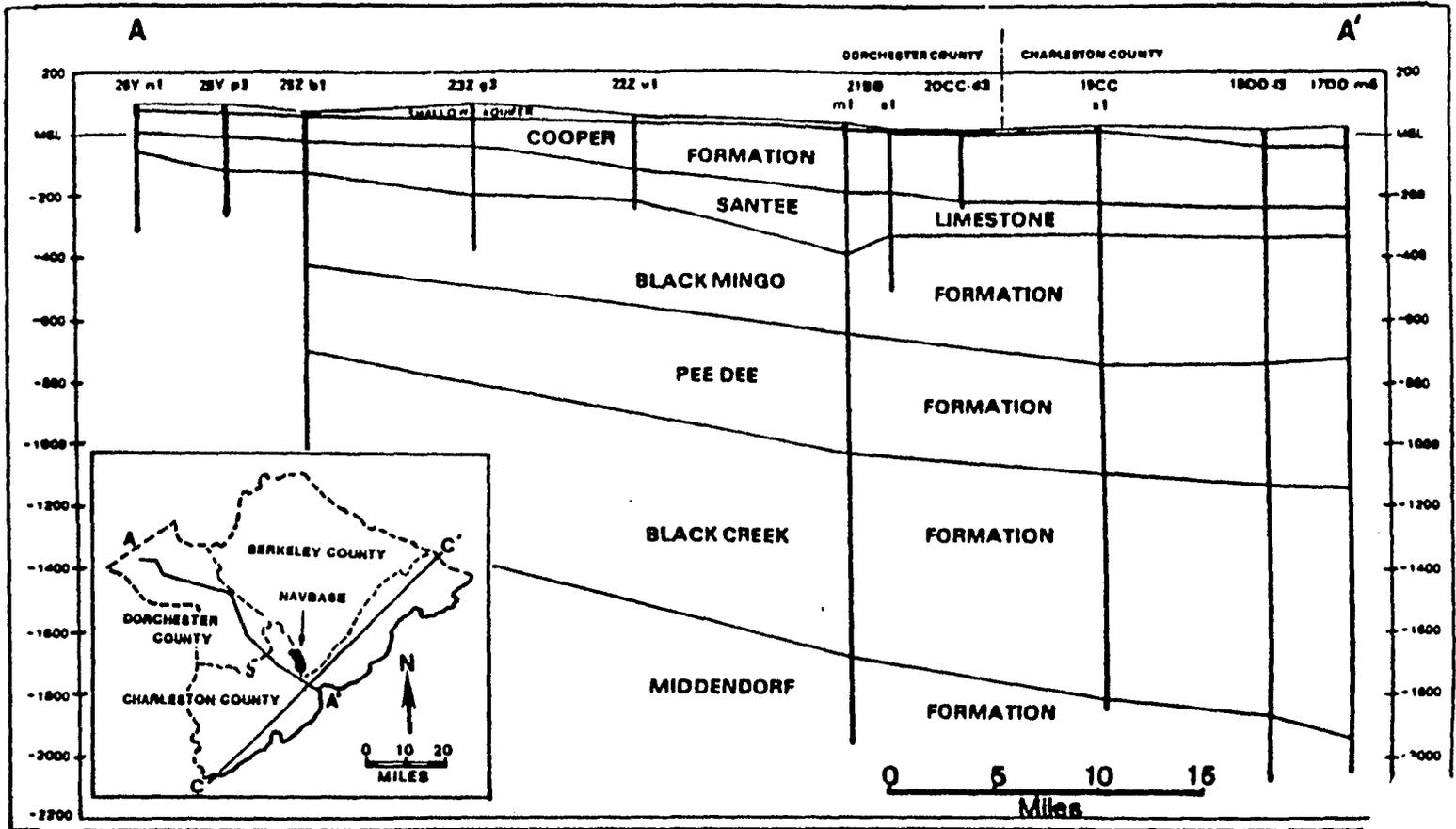
Another ditch exists directly northwest of the underground outfall culvert of the main drainage outfall. This canal is oriented in a perpendicular fashion to, and drains southeast directly into the main drainage canal via a culvert. The small canal collects runoff from the surrounding areas.

2.3.4 Regional Geology Geology of the Charleston area is typical of the southern portion of the Atlantic Coastal Plain. Cretaceous and younger sediments thicken seaward and are underlain by older igneous and metamorphic basement rock (Figure 2-4). Surface exposures at the shipyard, in those limited areas which remain undisturbed, consist of recent and/or Pleistocene age sands, silts, and clays of high organic content. These surface soils are underlain by a clastic calcareous clay known as the Cooper Marl. The Cooper Marl is, in turn, underlain by the Santee limestone and sequentially older rock formations. A generalized north-south cross section passing through the approximate center of the base is shown in Figure 2-5.

2.3.5 Soils Surface soils at the naval base have been extensively disturbed. Aboriginal soils consist of fine-grain silts, silty sands, and clay, typical of a terrigenous tidal marsh environment. Much of the southern portion of the base has been filled using dredged spoil consisting primarily of an unsorted mixture of sands, silts, and clays. Most of the remainder of the naval base has been either filled or reworked.

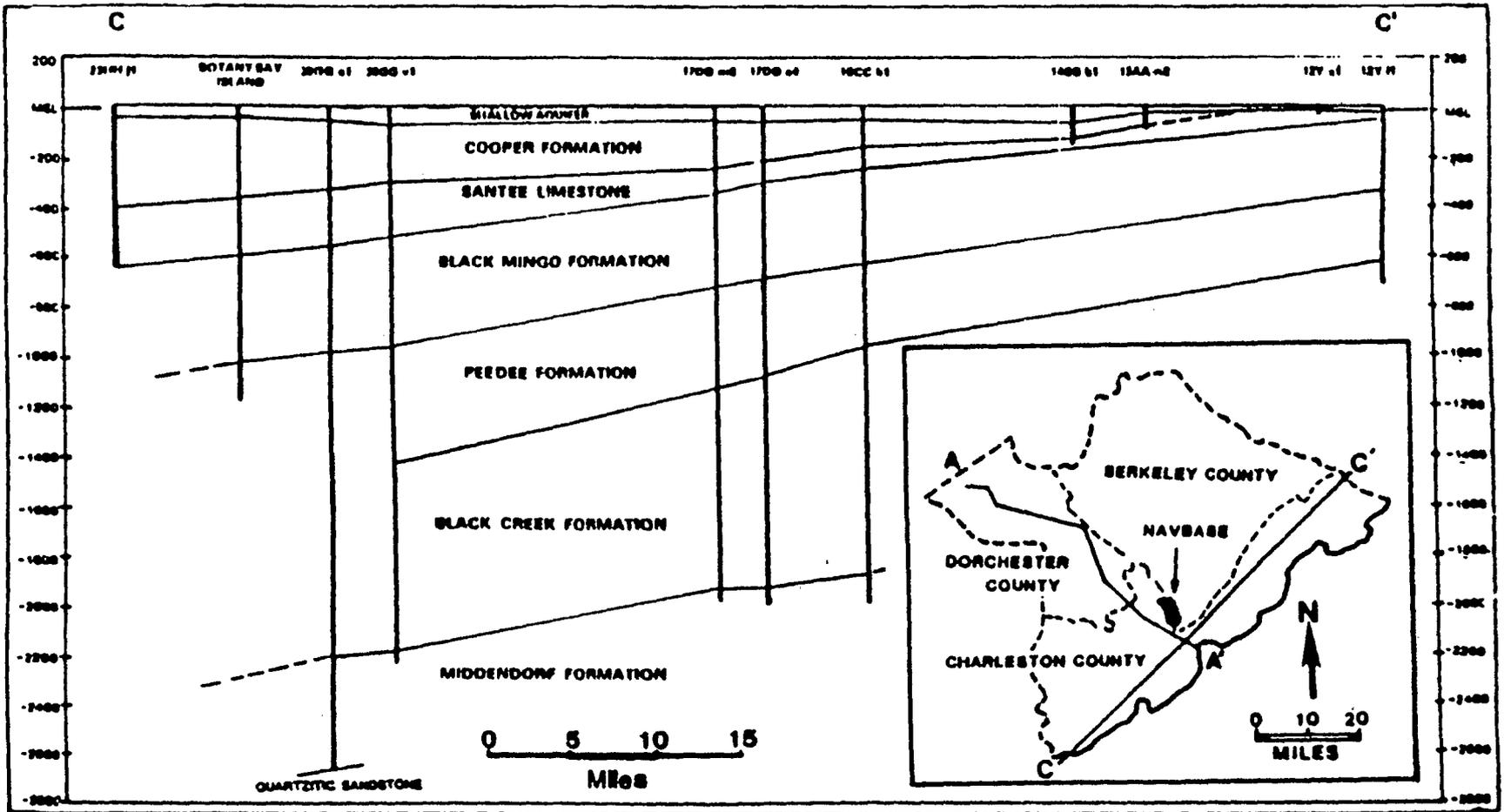
2.3.6 Hydrogeology Two distinct aquifers exist beneath the Charleston Shipyard, a deep confined aquifer in the Santee Limestone, and a shallow water aquifer located within the near surface sediments. Both the shallow aquifer and the Santee Limestone aquifer function as potable water supplies in other areas of the general region. The shallow aquifer is not developed

Figure 2-4. Regional geologic cross-section (NW-SE).



SOURCES: PARK, 1985; ESE, 1988

Figure 2-5. Regional geologic cross-section (SW-NE).



SOURCES: PARK, 1985; ESE, 1988

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either at or in the vicinity of the naval base. Deeper water from the Santee Limestone (in the vicinity of the naval base) is not suitable for potable supply; total dissolved solids range from 1,000 to 1,500 ppm. The Santee is used both on base and nearby for non-potable purposes.

The Cooper Marl, in the Charleston area, is essentially impermeable and acts as an upper confining layer for the Santee Limestone aquifer. The top of the Santee Limestone aquifer has a groundwater potentiometric elevation of approximately 15 feet MSL. The hydraulic gradient is generally towards the southeast. Water from the confined aquifer of the Santee Limestone formation has an upward potential through the Cooper Marl. This upward potential protects the Santee from any potential surface contamination.

Groundwater in the shallow aquifer beneath the base flows north and east into the Cooper River and south and west into Shipyard Creek due to the gently sloping topography away from the center of the base. Groundwaters in the immediate vicinity of Noisette Creek flow into it. The water table is generally within three to seven feet of the land surface although at DFSP it is even shallower. The shallow groundwater table, continually but slowly, discharges into Shipyard Creek, to the Cooper River, and to a lesser extent, into Noisette Creek. The water table mounds slightly beneath DFSP producing slow, radial flow.

2.3.7 Demography and Land Use Areas in the vicinity of the shipyard are mature urban having been long developed for commercial, industrial, and residential land uses. Commercial areas are primarily located west of the naval base, while areas north of the base and southwest, along the west bank of Shipyard Creek, are primarily industrial.

The west bank of Shipyard Creek has been used by heavy industry for many years. Railways have served the area since the early 1900's. Chemical, fertilizer, oil refining, metallurgical, and lumber operations have existed in the area since that time.

The east bank of the Ashley River is also dotted with industry. In contrast the east bank of the Cooper River is undeveloped and contains extensive wetlands, particularly along Clouter Creek and Thomas Island. Active dredge spoil disposal areas are located on Naval property between the Cooper River and Clouter Creek, and on the southern portion of Daniel Island and Drum Island.

2.3.8 Ecology Ecology in the vicinity of the naval base is typical of southeastern/coastal/ urban relationships. Urban fauna and flora typify the area. Although historical records indicate endangered species exist in the general region, none would be expected to use habitats present within the DFSP.

2.4 NATURE AND EXTENT OF CONTAMINATION.

2.4.1 Composition Former tanks G, H, and J were used for storage of fuels including diesel fuel, Nay Distillate, and Navy Special Fuel Oil (NSFO). Leakage from tanks G and H in 1974 and from tank J in 1955, 1979, and 1982 is thought to be the source of the petroleum products that make up the contamination. Analytical results suggest that only higher molecular weight petroleum compounds and metabolites remain in soils and groundwater beneath the site; headspace organic vapor analysis of samples collected during the most recent sampling found virtually no measurable soil vapors.

2.4.2 Sources Petroleum contamination beneath the site resulted from leakage of fuel from tanks G, H, and J. Tank J was found to be leaking in 1955 and was consequently deactivated from service. The tank was relined in 1979 but attempts in 1979 and 1982 to get it to hold fuel were unsuccessful.

Tanks G and H began leaking in 1974. The onset of leakage coincided with a change in tank use from NSFO storage to Navy Distillate storage. Navy Distillate is less viscous. An attempt to use the tank for diesel fuel storage in 1975 also failed due to leakage.

All three tanks have been disassembled and removed from site. The concrete pads and surrounding berms remain.

2.4.3 Extent in Soils ESE determined during its 1986 investigation that the areal extent of petroleum contaminated soils in the vicinity of pads G and H was approximately 49,800 square feet (corrected to 172,000 ft²). The vertical contaminated soil interval was estimated to be approximately eight feet, based on visual and olfactory detections noted during borehole advancement and soil sample retrieval activities. The areal extent of petroleum contaminated soils in the vicinity of pad J was determined by ESE to be approximately 6,000 square feet (corrected to 20,700 ft²). The vertical extent of soil contamination was estimated to be approximately four feet.

KEMRON installed nine soil borings during this investigation. The borings were installed near former tanks G, H, and J, that is, in the zone of petroleum contamination found by ESE during the initial characterization study. The purpose of these borings was to determine the vertical

extent of soil contamination in the vicinity of pads G, H, and J. Borehole locations are shown on Figure 2-2. Serendipitously, these borings found that the contamination extends neither horizontally nor vertically as far as had been supposed.

Petroleum contaminated soils were found in boreholes #6 and #7, inside the bermed area surrounding pad G. The areal extent of contaminated soils surrounding pads G and H appears to be 30,000 to 40,000 square feet. The approximate area of contaminated soils surrounding pads G and H is illustrated in Figure 2-6. The area of contaminated soils, as determined during the initial assessment study in 1986-87 is also shown in Figure 2-6.

Petroleum contamination was detected in soils retrieved from borehole #6 at depths of two, four, five, and eight to ten feet below surface, and from borehole #7 at depths of two and six feet below surface. The interval of soil sample retrieval within boreholes #6 and #7 and the associated lab results are shown in Table 2-1. Boreholes #6 and #7 are respectively located approximately 65 feet southwest and 15 feet northwest of pad G. The vertical extent of petroleum contaminated soils detected within the sample area ranges from intermittent intervals of two to eight to ten feet below surface. The estimated vertical extent of petroleum contaminated soils in the area beneath pads G and H is illustrated in Figures 2-7 and 2-7a.

The estimated volume of contaminated soils in the area beneath pads G and H is 100,000 to 200,000 cubic feet, or not more than approximately 7,000 cubic yards. This estimated value is much smaller than the estimate of 50,900 cubic yards of contaminated soils reported by ESE.

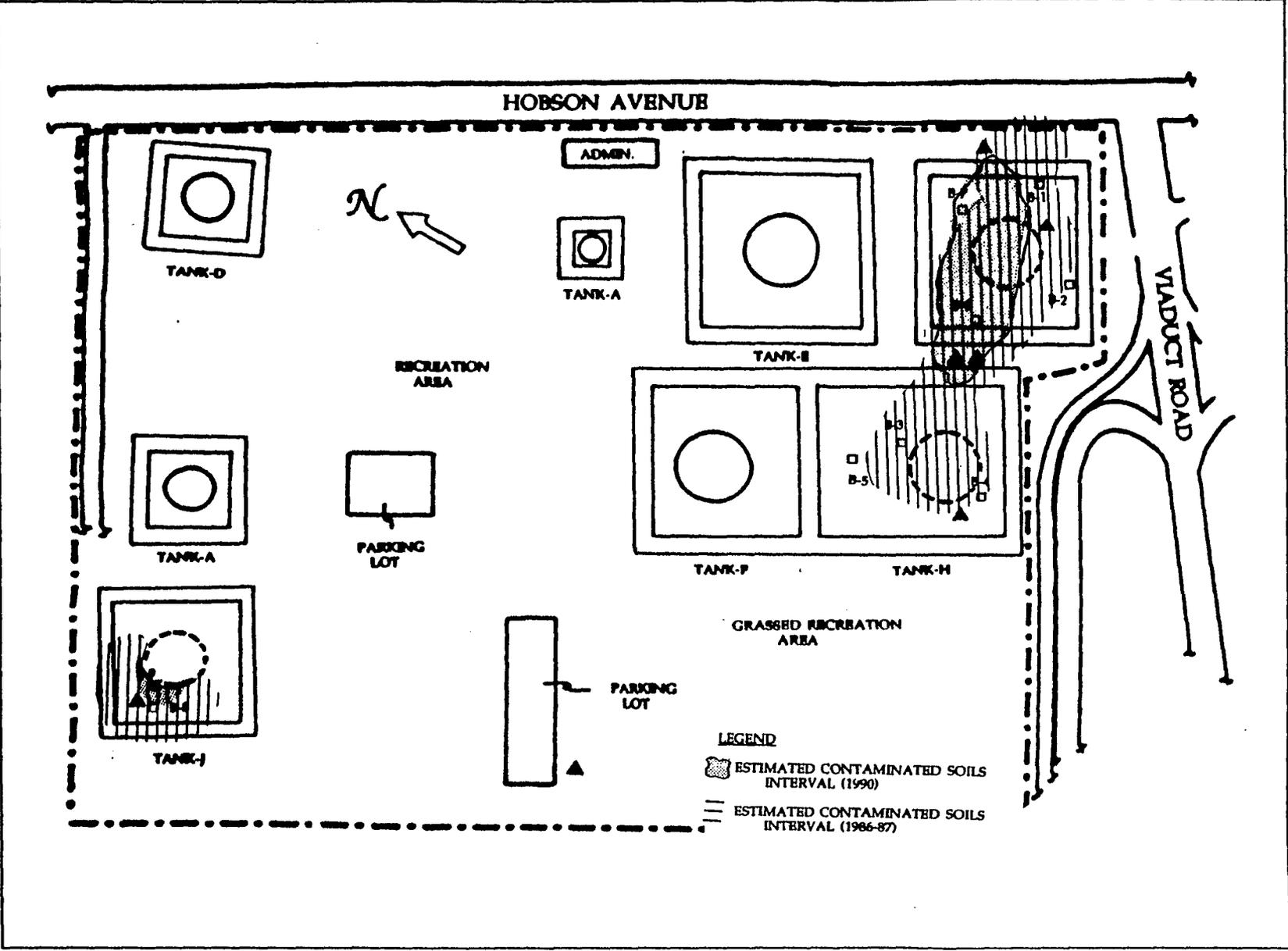


Figure 2-6. Estimated intervals of soil contamination (1986/87-1990).

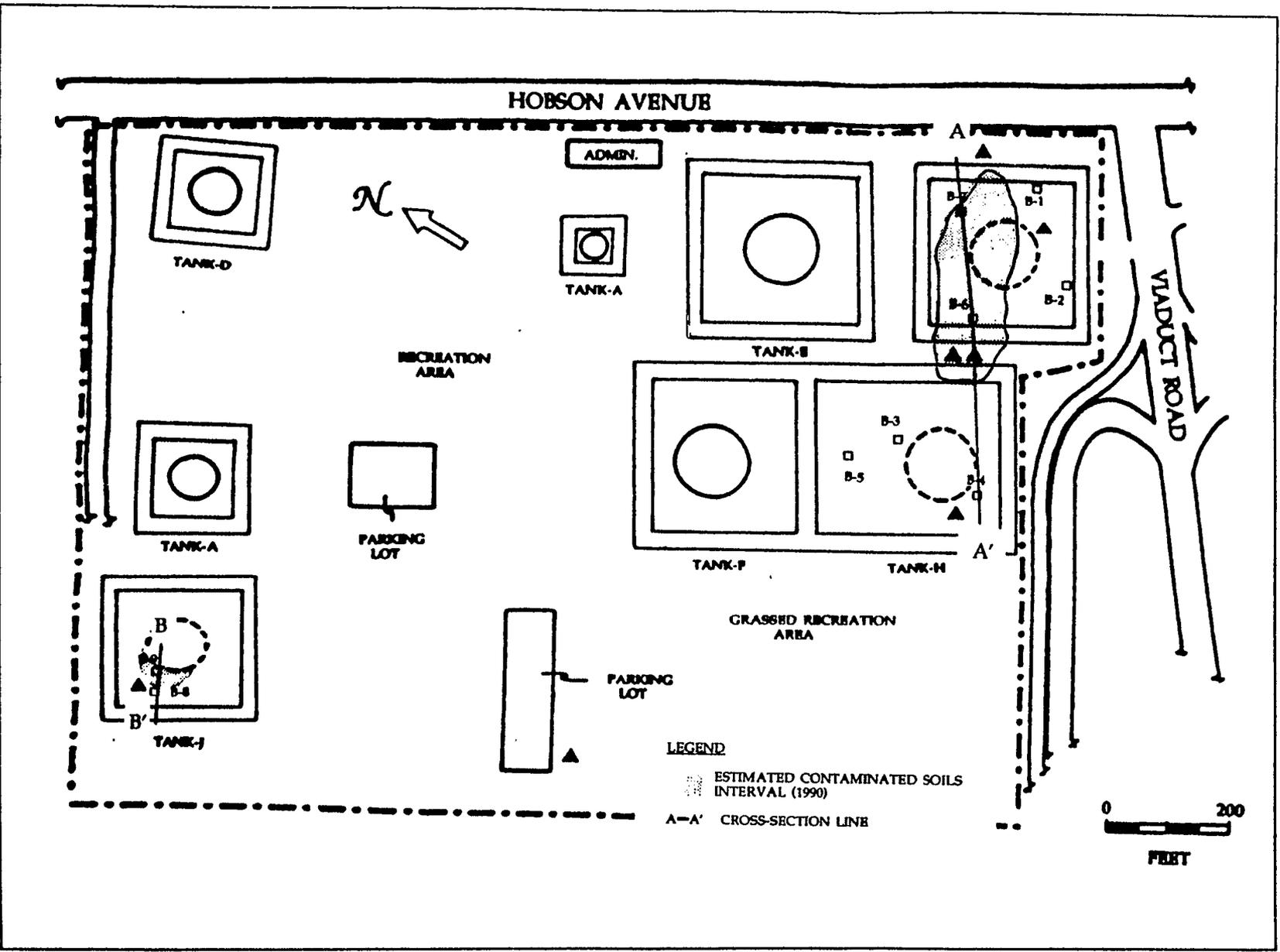
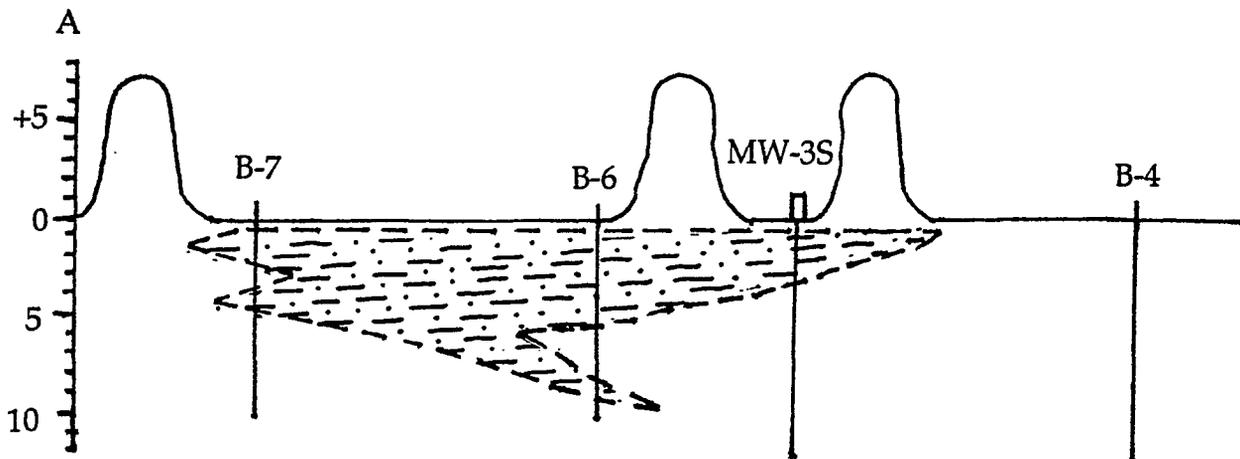
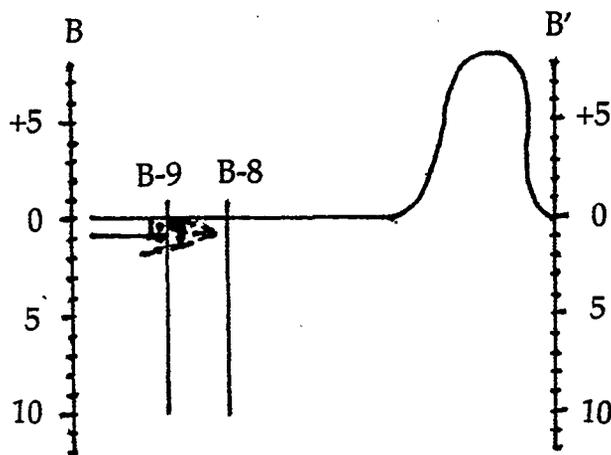


Figure 2-7. Cross section location map.

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A'



NE  SW



LEGEND

HORIZONTAL SCALE : 1" = 100'

VERTICAL SCALE : 1" = 10'

 ESTIMATED VERTICAL EXTENT OF SOIL CONTAMINATION

Figure 2-7a. Estimated vertical extent of petroleum contaminated soils.

Petroleum contaminated soils were found to be present within borehole #9, which is located inside the bermed area, approximately 25 feet west of concrete pad J. The areal extent of contaminated soils surrounding pad J is estimated at 2,500 square feet. The areal contaminated soils interval surrounding pad J is illustrated in Figure 2-2. The vertical extent of petroleum contaminated soils detected within the sampled area extends to a depth of two feet below surface. The intervals of soil retrieval in borehole #9 and the associated lab results are shown in Table 2-1. The vertical contaminated soils interval found to be present beneath pad J is illustrated in Figure 2-7a.

The estimated volume of contaminated soils present beneath pad J is 5,000 cubic feet, or approximately 200 cubic yards. This estimated value is also much smaller than the earlier estimate of 3,100 cubic yards.

2.4.4 Extent In Groundwater ESE determined during its 1986 and 1987 investigations that free phase and dissolved petroleum had migrated into the groundwater in the vicinity of tanks G and H. A 1/2 inch layer of dark, viscous petroleum product was observed floating on the groundwater in monitoring well 3S (Figure 2-1), on 11 August 1986. TPH concentrations ranging from 341 $\mu\text{g}/\text{l}$ to 130,000 $\mu\text{g}/\text{l}$ were detected in monitoring wells 3S, G-1, and H-1 (Figure 2-1) in 1986 and in wells 3D and 3S in 1987. These monitoring wells are located adjacent to pads G and H. No TPH was found in the remaining monitoring wells. PAH contamination was detected in all groundwater samples retrieved from on-site monitoring wells during the ESE investigation. Significant PAH contamination was found to be limited to the immediate vicinity of pads G and H. Although PAH compounds were detected in groundwater samples retrieved

30-Dec-1993 04:51:56am

from the remaining on-site monitoring wells, the levels of contamination were very low in comparison.

ESE reported a vertical attenuation in total PAH concentrations between shallow monitoring well 3S (1,851 µg/l) and the adjacent, deeper monitoring well 3D (70 µg/l). Similar horizontal attenuation of groundwater PAH contamination was reported between monitoring well 3S (1,851 µg/l), and the hydraulically downgradient monitoring wells G-1 (74 µg/l) and 2 (10 µg/l).

KEMRON resampled the seven on-site monitoring wells during this investigation. The purpose of the resampling was to obtain data to determine the current magnitude of groundwater contamination beneath the site. Laboratory assays performed on these samples found much lower TPH and PAH concentrations indicating that groundwater contamination beneath the site is not as extensive as it was during the 1986/87 investigation.

No free phase petroleum product was observed in the monitoring wells. A TPH concentration of 1.4 mg/l was detected in monitoring well #2. This monitoring well is located adjacent to pad G. No TPH was detected in the remaining monitoring wells.

Total PAH concentrations of 5 µg/l and 57 µg/l were detected in groundwater samples retrieved from monitoring wells G1 and 3S, respectively. Groundwater sample laboratory results are shown in Table 2-2 and in Appendix C. These monitoring wells are also located adjacent to pad G. The sole BTEX assay, conducted on a groundwater sample retrieved from monitoring well 3S, found nothing.

A notable decrease in petroleum contamination has apparently occurred in the groundwater beneath the site. This decrease is shown by a comparison of the laboratory results from samples retrieved during the 1986-87 and 1990 investigations, as described in the preceding paragraphs.

2.4.5 Surface Water and Sediments ESE retrieved surface water and sediment samples from the ditch and outfall located southwest of pad J (Figure 2-1), during their 1986 investigation. No petroleum contamination was reported to have been detected within the surface water samples. TPH contamination ranging from 43.9 mg/kg to 268 mg/kg was reported within the surface sediment samples retrieved from the ditch and the outfall. Petroleum contaminants detected in surface sediments were reported by ESE to have been a probable result of historical fuel releases in the area. Because this sediment contamination is not connected to either groundwater plume, it appears most likely due to storm runoff during periods when contamination existed at the land surface.

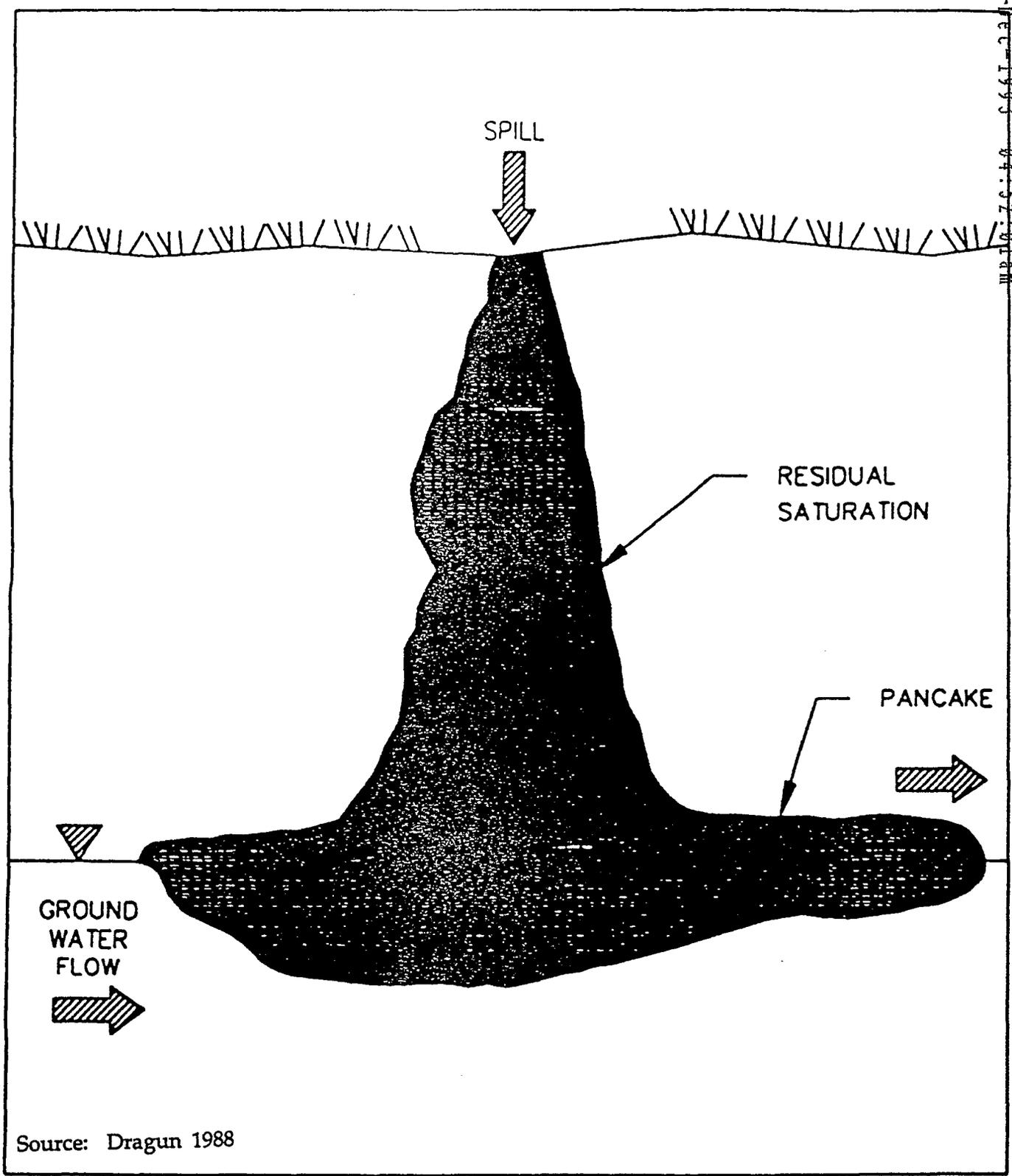
2.4.6 Air Air quality has not been assessed at this site. Air at the site is not believed to have been impacted due to the nature of the petroleum contamination.

2.5 CONTAMINATION FATE AND TRANSPORT.

2.5.1 Transport Mechanisms Navy distillate and diesel fuel are similar fuels and are transported by the same mechanisms. Dragun (1988) summarized the transport of bulk hydrocarbons in soil.

"Light[er than water] bulk hydrocarbon will migrate downward in unsaturated zone soil due to gravity and capillary forces. If the volume of released hydrocarbon is large, such as those related to catastrophic spills, maximum lateral spreading and downward flow occurs with all soil pores being saturated with hydrocarbon. Figure [2-8] illustrates the hydrocarbon distribution most often displayed in the published literature. The distribution illustrated in Figure [2-8] is valid for major gasoline spills or tanker ruptures, but not for slow leaks; this case will be discussed later in this chapter. The downward migration of light bulk hydrocarbon will eventually cease because (a) the mobile light bulk hydrocarbon will be transformed into residual saturation, or (b) it will encounter an impermeable bed, or (c) it will reach the capillary fringe." The capillary fringe is the lower portion of the vadose zone immediately above the water table in which 50% of the interstitial space of the soils is filled with water. The interstitial water is under pressure less than that of the atmosphere and is held above the water table by surface tension. "Each situation is described in greater detail below.

As a mass of bulk hydrocarbon migrates beyond a unit mass of unsaturated zone soil, a small amount of the total hydrocarbon mass will remain attached to these soil particles via capillary forces. The bulk hydrocarbon that is retained by soil particles is known as immobile or "residual saturation." The maximum amount of bulk hydrocarbon that can be retained by a soil is known as residual saturation capacity. Residual saturation can potentially reside in soil in this state for years. If the migrating mass of bulk hydrocarbon is small relative to the soil surface area, the mass of bulk hydrocarbon will be eventually exhausted as it is converted into residual saturation. When conversion is complete, downward migration ceases.



Source: Dragun 1988

Figure 2-8. Gravitational transport of petroleum release.

The volume of soil required to immobilize a mass of bulk hydrocarbon depends upon the porosity of the soil and the physical properties of the bulk hydrocarbon...

In general, the residual saturation capacity of soils is about 33 percent of their water-holding capacity. The maximum residual saturation for light oil and gasoline is 0.1; for diesel and light fuel oil, 0.15; for lube and heavy fuel oil, 0.20...

If a mass of bulk hydrocarbon which is migrating downward encounters an impermeable [sic] layer, it will spread laterally until (a) the bulk hydrocarbon is transformed into residual saturation, or (b) it migrates past the lateral extent of the impermeable layer. If the latter situation occurs, vertical migration will commence at the point where the lateral extent of the impermeable layer has ceased. Downward migration will continue until (a) the bulk hydrocarbon is transformed into residual saturation, (b) another impermeable barrier is encountered, or (c) the bulk hydrocarbon encounters the capillary fringe.

Percolating water, in unsaturated zone soil containing residual saturation, can initiate the downward migration of hydrocarbon...This phenomenon is expected to continue until the hydrocarbon which can migrate by this process is depleted from soil pores. Then, percolating water will generally move around the hydrocarbon with minimal disturbance.

As light hydrocarbon enters the capillary fringe, it will bypass the smaller, water-filled pores and continue migrating downward through larger pores which do not contain water. Downward migration will end when the light bulk hydrocarbon encounters water-saturated

large pores. Then, the light bulk hydrocarbon begins to migrate laterally over the water table in a layer roughly as thick as the capillary fringe. This layer of light hydrocarbon will assume the shape of a "pancake"; this layer of hydrocarbon is commonly known as the pancake layer (see Figure [2-8]).

If a relatively large volume of bulk hydrocarbon reaches the water table, its weight will be sufficient to collapse the capillary zone and depress the water table. The amount of depression will depend upon the amount of light bulk hydrocarbon present. Since the specific gravity of gasoline and light oils is approximately 0.70 to 0.80, about 75 percent of the hydrocarbon pancake will be below the depth of the original water table. Due to the force of buoyancy from below and the force of additional light hydrocarbon descending from above, the pancake will tend to spread laterally as rapidly as soil conditions will permit. Initially there may be sufficient head pressure to cause the light hydrocarbon to move a small distance up gradient, but the greatest spread will occur in the down gradient direction. The pancake will migrate until it reaches residual saturation or until it reaches a zone of ground water discharge. As the pancake migrates laterally, water in the capillary fringe will impede its movement because water occupies pore space. In the upper section of the capillary fringe where relatively small amounts of water are present, bulk light hydrocarbon comprising the pancake will migrate laterally. However, in the lower section of the capillary fringe where relatively large amounts of water are present, the pancake migrates laterally at a negligible rate. Light hydrocarbon migration over groundwater can be measured directly...

The pancake will fluctuate vertically as the water table fluctuates vertically in response to seasonal changes and to short-term rainfall events. The total amount of mobile

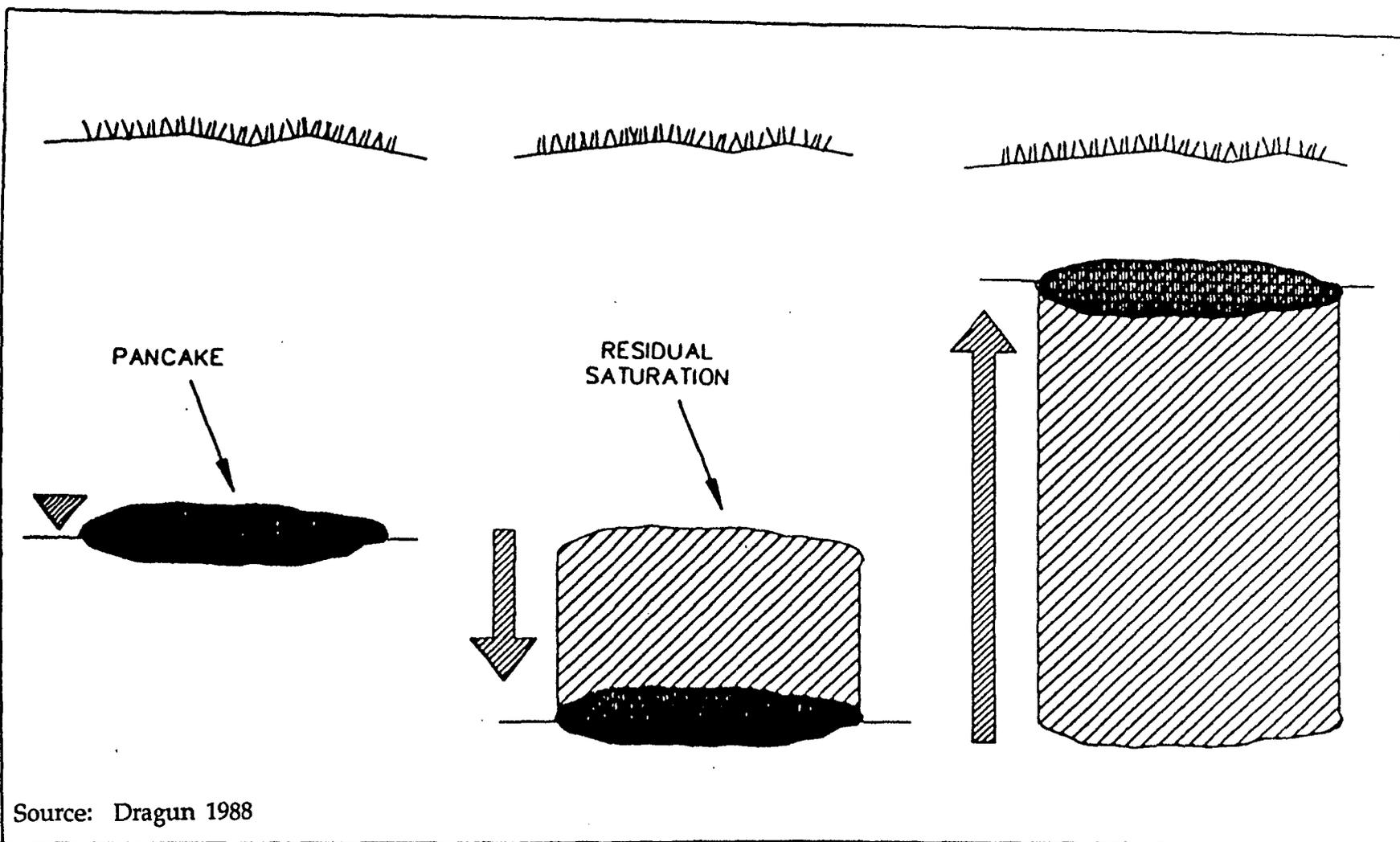
hydrocarbon in the pancake will decrease as fluctuating mobile hydrocarbon coats soil particles and transforms into residual saturation (see Figure [2-9]).

Constituent transport also occurs due to the movement of groundwater in which those constituents are dissolved. Although very few fuel constituents have appreciable aquatic solubility, sufficient solubility exists for the more carcinogenic components to adversely impact groundwater. In general, such chemicals do not migrate at the groundwater flow velocity but at some slower rate depending on the chemical affinity of particular constituents for soil particles (i.e., the distribution coefficient) and on other factors. Nonetheless, groundwater velocity sets an upper bound on contaminant transport rates. At DFSP, due to the low hydraulic gradient of $<.02$ cm/cm (ESE, 1988), this advective transport cannot be more rapid than several tens of feet per year.

2.5.2 Attenuation Mechanisms The total mass of contaminants at DFSP is continuously decreasing due to a variety of mechanisms. The most important of these is biological catabolism although diffusion and evaporation also have a role.

Evaporation is usually most significant in the case of fuels having lower average molecular weights than those released at DFSP. However, it has some impact on all fuel releases. Fuel components with significant vapor pressure evaporate into air pockets in the vadose zone until equilibrium is established. As soil gases communicate with the atmosphere, however imperfectly, vadose zone vapors continually leak from the ground surface. This gradually shifts the equilibrium established at evaporative surfaces in the vadose zone causing additional net evaporation and a net loss in the total mass of contaminants present.

Figure 2-9. Transformation of mobile hydrocarbon into residual saturation.



Diffusion is generally considered to reduce peak concentrations and spread out the contamination, but not to result in any net loss of contaminant mass from the system. Nonetheless, net mass loss occurs due to diffusion. Consider that surface, approximately pan shaped, which separates soils having contaminant concentrations of sufficient magnitude to require remediation from those soils below the clean-up criteria. Diffusion across this surface results in a net loss of contaminants from the area requiring remediation.

The most important attenuation mechanism at DFSP is biological catabolism or degradative metabolism. Conceptually, biological degradation refers to the uptake and destruction of constituents by any organism. As a practical matter, among organisms, only soil microbial populations play any significant role. And in the case of bulk hydrocarbons, uptake is a secondary stage which follows extra-cellular breakdown of higher molecular weight constituents into moieties which can be transported across the cell wall and cell membrane. Extra-cellular breakdown is effected by secretion of enzymes into the extra-cellular medium.

The rate of biodegradation is a function of many factors. These factors are discussed in detail in Appendix D. Among them are temperature, pH, moisture content of the soils, the total mass of microbes actively respiring, availability of oxygen and nutrients, the mix of species in the microbial population, and, through mechanisms not yet fully elucidated, the history of the microbial population as it relates to prior exposure of that population to the contaminants of interest. At DFSP, most all of these factors are favorable for biodegradation; the contamination represents an abundant food and energy supply for indigenous microorganisms. Ambient temperature, pH, moisture content, the age of the release, and other factors at DFSP are as favorable as one finds. Rate-limiting factors are the availability of nutrients (which, being

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limited, prevent expansion of the microbial population) and the flux of oxygen through diffusion into the near-surface environment (which limits the rate at which carbon dioxide can be formed). Carbon dioxide and water are the final breakdown products of most hydrocarbons undergoing biodegradation in the near-surface environment.

2.5.3 Plume History Contaminants, released to the environment at DFSP, have been transported by the mechanisms described in paragraph 2.5.1, except that, since the water table is very shallow, no impermeable layer delayed movement of the spill to the ground water surface. Since release, contaminant concentrations have attenuated as the plume was dispersed during transport. Contaminant concentrations have also attenuated by the mechanisms described in paragraph 2.5.2.

Contamination of the soil and groundwater beneath the site occurred due to fuel leakage from former tanks G, H, and J. Tanks G and H were constructed of concrete. Tank J was constructed of steel resting on a concrete support pad. These former tanks were engineered to accommodate storage of extremely viscous fuels (the equivalent of #6 fuel oil).

Contamination of the environment occurred when less viscous fuels were stored in the tanks. The fuels flowed through leakage in the steel, weeped through the porous concrete base pads of the former tanks, and migrated into the soils beneath the tanks. The soils beneath the site consist of a relatively porous heterogeneous mixture of sand, silt, and clay in varying percentages.

During the period immediately following each major release, fuels migrated quickly to the water table and then, much more slowly, pancaked over a wide area. Over time, water table fluctuations spread the contamination vertically converting the floating pancake into residual saturation. This effectively limited further spread of the contamination and resulted in an irregular, disk-shaped plume bound to shallow soils.

Over the years, most volatile constituents were lost from the plume. Also, the indigenous microbial population acclimated to the presence of the fuel and began to degrade it. It would be difficult now to reconstruct the historic rate of biodegradation at the site or say how far it has progressed. However, the substantial reduction in plume size since ESE's work at the site several years ago suggests that biodegradation is the major factor currently affecting plume size and geometry.

In August 1986, ESE found one half inch of visibly degraded free floating petroleum in the heart of the plume. By May 1987, only a sheen remained. Today, even the sheen is gone. Between August 1986 and May 1987, TPH concentrations went down substantially in three wells and up slightly in one. Today, only a trace can be found in a single well. ESE found visual and olfactory evidence for a pancake covering almost four acres but found measurable TPH only within a smaller area. Today, measurable TPH exists only in an area which is smaller still. The concentration of PAH constituents has also gone down substantially with time.

This plume shrinkage cannot be attributed to either dispersion or diffusion. Losses due to volatilization, given the high molecular weight of the released constituents, can account for only

a small fraction of the shrinkage. Given the favorability of site conditions to biodegradation, it is reasonable to conclude that the documented plume shrinkage is due almost entirely to biological mechanisms.

2.5.4 Plume Fate Ultimately, the contamination at DFSP will go away on its own. Petroleum simply cannot persist long in the near-surface environment. However, the already substantial age of the plume implies that it will persist for many years unless action is taken to remove or destroy it.

Since no contamination remains in the form of a floating layer of petroleum, further spread of the contamination through pancaking will not occur. Diffusion, of course, will continue at a slow rate as will advective transport of dissolved constituents. These spreading mechanisms are opposed by attenuation mechanisms, primarily biodegradation. At some point, the spread and attenuation balance or cancel and the groundwater plume geometry comes into stable equilibrium. This point was probably reached some time in the past. Following that point, the ground water plume gradually shrinks.

If no action is taken, soil contamination will gradually decrease, primarily due to biodegradation. Nonetheless, constituent concentrations will remain above applicable criteria for years, perhaps decades.

2.6 RISK ASSESSMENT. This section describes the likelihood of harmful impacts of the no action alternative on human health and the environment. Describing the risk of such harm involves estimating the chance that various individuals, populations or ecosystems, would be

exposed to DFSP contaminants if no action is taken. The likely concentration and duration of potential exposures are also considered. Finally, the chance that those exposures would produce toxicologic harm is estimated.

2.6.1 Human Health Potentially exposed persons include base personnel and nearby residents.

Dermal contact is unlikely but must be assumed to be possible since institutional controls (permanent closure) to prevent exposure are not in place. The area is fenced and access is limited to authorized personnel. No significant contamination currently exists at the surface. Hence, dermal contact is unlikely. Nonetheless, dermal contact might occur if site soils are disturbed, for example, during construction. Under any reasonable scenario, the duration of such exposures would be short. Assuming dermal exposure to the most contaminated soils, some transcutaneous absorption would occur. Since some constituents are carcinogenic, any such exposure must be assumed to incrementally increase that receptor's risk. Adequate data are lacking to quantify this incremental increase, but using conservative assumptions, it is found to be well below the 10^{-6} risk level typically regulated.

The USEPA Office of Water, Ambient Water Quality Criteria for Polynuclear Aromatic Hydrocarbons (45 FR 79318) reports a 10^{-5} lifetime cancer risk at a dose of 0.028 $\mu\text{g}/\text{l}$ using the older and more conservative Clean Water Act risk assessment procedures. Multiplying 0.028 $\mu\text{g}/\text{l}$ by 2 liters, 365 days and 70 years yields a total dose of 1430 μg . In order to absorb 1430 μg of PAH dermally, one would have to absorb all of the PAH in 12 1/2 pounds (5670 grams) of the most contaminated soil (see Table 2-1). The necessary dermal exposure to produce this magnitude of absorption does not appear reasonably possible.

Direct ingestion of soil contaminants is unlikely under any reasonable scenario but cannot be ruled out. Without detailed analysis, we feel safe in stating that this risk is less than that posed by dermal contact.

Ingestion of constituents carried by groundwater is impossible so long as there are no users of the shallow aquifer. Nonetheless, it must be presumed that wells might be constructed. (These assumptions are required by EPA risk assessment procedures; they represent "worst case" conditions unlikely to occur but impossible to rule out.) Assuming no attenuation occurs during transport to such a well, the groundwater user would be exposed to PAH constituents near the 10^{-5} lifetime cancer risk level. Since such levels are set conservatively, we may assume this risk is acceptable. The assumption of no attenuation is clearly counterfactual. Current attenuation mechanisms reduce PAH concentrations from their peak in the heart of the plume to non-detectability at the property boundary. Since PAH concentrations are decreasing throughout the plume, risk of PAH exposure is limited to potential on-site wells near the heart of the plume, even in the worst case hypothetical.

Inhalation exposures are immeasurably low under all scenarios.

2.6.2 Environment Potential environmental receptors, other than soil organisms in the zone of contamination, are limited to species using surface waters and wetlands adjacent to DFSP. Discharge of contaminated groundwater to nearby surface waters would presumably impact these receptors, however negligibly. However, groundwater concentrations are so low that we could generate no scenario in which surface water contaminant concentrations exceeded ambient water quality criteria.

CHAPTER 3. DEVELOPMENT AND SCREENING OF ALTERNATIVES

3.1 REMEDIAL OBJECTIVES. This section discusses contaminant concentrations which must be achieved during remediation in order to protect human health and the environment and in order to meet relevant or applicable clean-up criteria. Contaminants of concern are those which have been detected in DFSP soils, groundwater and other media. DFSP media have been assayed for TPH, BTEX, and PAH. TPH and several PAH constituents have been detected; BTEX constituents have not been detected (with one low level exception). Details of the nature and extent of contamination are provided in section 2.4. Contaminant fate and transport are discussed in section 2.5. Potential routes of exposure and toxicity of detected compounds are reviewed in section 2.6.

3.1.1 Protection of Human Health In order to fully protect human health, PAH ought to be non-detectable in drinking water. PAH concentrations should at least be held below the 1 in 100,000 lifetime cancer risk level of 0.028 µg/l, if they cannot be eliminated entirely. PAH concentrations in soils are relevant in evaluating drinking water risks to the extent that PAH constituents partition into the groundwater. Any clean-up which is protective of groundwater will be protective of dermal contact, ingestion, and inhalation pathways as well.

Drinking water criteria have not been set for TPH. However, soil concentrations less than 10 mg/kg are considered protective of groundwater. This criterion is also considered protective with respect to dermal contact, ingestion and inhalation pathways.

3.1.2 Protection of the Environment Ambient water quality criteria have not been set for PAH as a class but have been set for some PAH constituents. Appropriate protection against chronic toxicity resulting from exposure to acenaphthene is found at the following levels: 1700 µg/l for freshwater animals, 520 µg/l for freshwater algae, 710 µg/l for saltwater animals, and 500 µg/l for saltwater algae. Appropriate protection against chronic toxicity resulting from exposure to fluoranthene is found at 3980 µg/l for freshwater aquatic life and at 16 µg/l for saltwater aquatic life. Appropriate protection against freshwater chronic toxicity resulting from exposure to naphthalene is found at 620 µg/l; protection against saltwater acute toxicity was found at 2350 µg/l. Criteria set for these three PAH constituents are suggestive of levels which are likely to be protective for other PAH constituents based on homology and bearing in mind that toxic effects are most likely additive. Environmental values should therefore be more than adequately protected if the human health protective remediation goal of 0.028 µg/l total PAH is achieved.

Ambient water quality criteria have not been established for petroleum hydrocarbons, but have been established for oil and grease and visible sheen. Achievement of the 10 mg/kg TPH standard for soil will be protective of surface water quality insofar as oil and grease standards are concerned, but could conceivably allow a visible sheen to develop. TPH concentrations in soils should be less than 10 mg/kg and should be sufficiently low to produce no visible sheen in order to protect the environment.

3.1.3 Applicable and Relevant Criteria DHEC has set no fixed numeric standards for clean-up of petroleum contaminated soils. Each site is considered on a case-by-case basis. Groundwater impacts must be kept below drinking water limits, but this is only a necessary, not a sufficient, condition. Sufficient conditions can only be developed following a quantitative risk assessment.

Sufficient data for a quantitative risk assessment is not available; the risk assessment portion of this document (section 2.6) is only qualitative.

We discussed this matter with Ms. Christine Sandford of DHEC's Charleston Underground Storage Tank program. Ms. Sandford has evaluated clean-up criteria at numerous Charleston area petroleum release sites. Her judgement is, that when rigorous numeric data are unavailable, clean-up criteria can be set using qualitative data and conservative assumptions. In her experience, soil clean-ups in the Charleston area need to achieve residual concentrations in the range of 5 to 10 mg/kg TPH in order to be protective of human and environmental factors, in the absence of hard data and a rigorous risk assessment. Her judgement is that 10 mg/kg TPH is an appropriate standard for the clean-up at DFSP based on the data currently available and conservative assumptions. Much higher levels could be approved with proper justification.

Until sufficient data is gathered to support a higher limit, we propose 10 mg/kg TPH in soils as the clean-up criterion at DFSP.

3.2 ALTERNATIVES. This section describes various remediation methods which could be used to remediate soil and groundwater contamination beneath the site. A variety of options was explored. Soils could be either cleaned in place or removed from the ground. The soils, if removed, would require either on-site ex situ treatment or off-site transport and disposal. Similarly, groundwater could be treated in place or removed from the ground. Remediation methods divide naturally into ex-situ and in-situ alternatives.

3.2.1 Ex Situ Alternatives Ex situ treatment methods require physical removal of contaminated soils from the zone of contamination and transport to a secondary location (which may be on-site) for treatment or disposal. Following excavation, contaminated groundwaters would remain and may require treatment. The groundwater remediation methods considered for this site are carbon treatment, discharge to a POTW without pretreatment, and the no action alternative. Ex situ soil remediation methods considered for this site are landfilling, thermal treatment, and biological treatment.

3.2.1.1 Groundwater Treatment and Disposal During excavation of contaminated soils, a shallow pit will be created. Initially, surrounding groundwaters will flow into this pit. Much of the removed soil will be too wet to transport or treat. Some means for dewatering such soils will need to be implemented. We assume, without detailed study, that soils could be staged adjacent to the excavation in a way that would allow them to drain into the pit. Waters removed from the contaminated soil piles will likely contain measurable petroleum constituent concentrations and may contain measurable TPH.

When soils are returned to the pit following treatment or when new fill is brought in, groundwaters in the pit will be displaced. If the pit is not pumped down during refilling, displaced groundwaters will migrate into surrounding soils. The volume of these displaced groundwaters should be sixty to eighty percent of the volume of soil returned to the pit.

One alternative for dealing with these waters is the no action alternative. Contaminant concentrations in the water may be sufficiently low that the water could be allowed to overtop the pit and flow across a grassed area to the drainage ditch. Overland flow is a well proven

technology for treatment of biodegradable organics (EPA 1981). Rapid refilling of the excavation would likely cause this overland flow. If such overland flow is impermissible, the no action alternative would require berming of the excavation prior to refilling so that waters escape the pit only through the pit walls and subsurface flow.

A second alternative for dealing with pit water, is to pump it to the sanitary sewer system. This would require prior approval from the POTW and that would require adequate analytical characterization. It might also require some minimal form of pretreatment, most likely, some means to prevent discharge of silt and other solids.

A third alternative is to treat pit water to remove regulated constituents. This could be done in several different ways but it appears likely that constituent concentrations will be sufficiently low to make activated carbon treatment most cost-effective. Treated water could be returned to the pit or discharged. If discharged, an NPDES permit would be required. Pretreatment to remove solids would be necessary to protect the carbon units from blinding.

Choosing among these alternatives is necessary only if soils are excavated. In situ treatment addresses soils and groundwater contamination simultaneously. If soils are excavated, the preferred alternative for groundwater treatment is simple discharge to the sanitary sewer system with pretreatment if necessary. The overland flow alternative, despite its parsimony and potential elegance, would require careful study to assuage reasonable concerns, which would cost more than potential benefits. The other no action alternative might be physically impracticable; pit walls could be blinded by suspended clay so that refilling the pit takes unreasonably long. Carbon treatment followed by discharge back to the pit becomes less and

less cost-effective as the pit contaminants become more dilute but might achieve sufficient concentration reductions to satisfy concerns regarding overland flow during refilling of the pit. If not, the same practicability problem results during refilling. Carbon treatment and surface water discharge is technologically simple and reliable, but subject to permitting procedures which typically require the better part of a year to complete. Hence, sewer discharge is preferred as not subject to these disadvantages. Sewer discharge with minimal pretreatment could be accomplished for approximately \$3,000.

3.2.1.2 Landfilling The ex situ landfilling remediation option would require excavation of the contaminated soils beneath the site. A large area would be required for soil storage, upon excavation, to allow for dewatering. Dewatering is required to lower the moisture percentage of the soils for landfill disposal. Purchase of clean soils would be required to backfill the excavations created by the removal of the contaminated soils from the site. Groundwater treatment (discharge to the Charleston POTW in the preferred alternative) is estimated to add \$3,000 to the cost of this alternative. Sampling and analysis of soils left in place to verify remediation and of removed soils to characterize them for disposal are estimated to add \$5,000 to the cost of this alternative.

3.2.1.3 Thermal Treatment The thermal treatment option would require excavation of the contaminated soils and dewatering as above with the establishment of a portable heat treating unit at the site. The portable heat treating unit in this alternative consists of a raw material hopper and screen, a conveyer belt system, a large rotary dryer, and a vapor devolatilization system. The hopper and screen are used to agitate and separate the soils to be remediated. The soils, after excavation and dewatering are sifted through the hopper and onto a conveyor belt

which transports them into a large rotary dryer. Volatile hydrocarbons and water in the soils are driven off in the rotary dryer and routed through the vapor devolatilization system. This system oxidizes organic vapors to carbon dioxide and water vapor. Soils are allowed to cool and then transported back to the site for backfill into the excavations. Air quality monitoring would be required during operation of the system to insure that the volatile organic compounds driven from the soils in the rotary dryer do not contaminate the ambient air. Random sampling of the remediated soils prior to backfilling would also be required to confirm reduction of contaminants to acceptable levels. Groundwater treatment (discharge to the Charleston POTW) is estimated to add \$3,000 to the cost of this alternative. Sampling and analysis 1) of soils left in place to verify complete excavation, and 2) of treated soil to verify clean-up are estimated to add \$7,000 to the cost of this alternative.

3.2.1.4 Biological Treatment The ex situ biological treatment method would require the construction of a bermed and lined treatment cell. Soils, following excavation and dewatering as before are transferred to the treatment cell. Nutrients are added by a spray distribution system. Air, drawn through the treatment cell, supplies oxygen. Systematic sampling and laboratory analysis would be conducted on soils in the treatment area. The soils would be backfilled into the excavated areas when laboratory results confirm that remedial efforts have reduced contaminant concentrations to acceptable limits. As before, separate groundwater treatment may be necessary. Groundwater treatment (discharge to the Charleston POTW) is estimated to add \$3,000 to the cost of this alternative. Sampling and analysis 1) of soils left in place to verify complete excavation, and 2) of treated soil to verify clean-up are estimated to add \$7,000 to the cost of this alternative.

3.2.2 In Situ Alternatives In situ treatment methods utilize biodegradation to remediate contaminated soils and groundwater beneath the site. The in situ remediation methods considered for this site are the no action alternative, landfarming/biostimulation, and subsurface biotreatment. Groundwater treatment options need not be considered if in situ soil remediation is performed. With in situ methods, groundwater treatment is an inseparable concomitant of soils treatment. However, in order to be assured that these alternatives do not adversely impact area groundwaters, an expanded monitoring well network is recommended (see paragraph 3.3.4). The cost of these additional wells is estimated to be approximately \$8,000.

3.2.2.1 No Action The no action alternative is a monitoring only alternative and relies on natural biodegradation to remediate the site. The alternative consists of periodic sampling and laboratory analysis of soil and groundwater beneath the site. The present value of this long term testing is estimated to be approximately \$20,000.

3.2.2.2 Landfarming/Biostimulation The landfarming/biostimulation option entails application of fertilizer to the zone of contamination. A moldboard plow (because it can reach greater depths than other plows) would then be used to turn and aerate the soils. The added fertilizer will have sufficient nitrogen and phosphorous concentrations to raise total nutrient concentrations in shallow groundwater beneath the site to 10 mg/l as nitrogen and 1 mg/l as phosphorous. Plowing of the soils, as described above will increase the flow of oxygen into subsoils and groundwater. The nitrogen and phosphorous nutrients will increase the active microbial mass, while the introduced oxygen will accelerate decomposition of the contaminants. A monitoring program consisting of periodic sampling and laboratory analysis of soil and groundwater beneath the site should be initiated if the landfarming/biostimulation alternative

is implemented (see paragraph 3.3.4). This program would monitor the effectiveness of the remediation and would monitor nutrients in the groundwater. It is estimated to add approximately \$10,000 to the cost of this alternative.

There are three keys to optimizing biostimulation at a site like DFSP. One is to maximize the flux of oxygen into contaminated soils. Another is to insure that sufficient nutrients for microbial activity are present. The third is to keep the actively degrading biomass in intimate contact with the contaminants to be degraded.

Maximizing the flux of oxygen into the soils is important because biodegradation of petroleum is essentially a series of oxidations of the carbon and hydrogen in the petroleum terminating in the production of carbon dioxide and water. Without oxygen, this oxidation cannot proceed. In landfarming, the oxygen flux into the soils is enhanced by plowing. This turns the soils to expose those which are oxygen-deficient to the air and opens up voids in the soil increasing diffusion rates.

The first turning of the soils will be accomplished using a backhoe; thereafter, a moldboard plow will be used. The backhoe is used initially for purposes of mixing described below. Plowing is conducted as frequently as possible, weather permitting.

Nutrient dosing is necessary in order to maximize the size of the degradative microbial community. An abundant food supply (i.e., the petroleum contaminants) is necessary but not sufficient for microbial growth and reproduction. Proteins and phospholipids of which microbes are largely composed cannot be manufactured by those microbes without nitrogen and

30-Dec-1993 04:53:16am

phosphorous. As a rule of thumb, microbes contain carbon, nitrogen, and phosphorous in ratios of 100:5:1; consequently, these elements must be supplied in approximately those ratios to create new biomass through growth and reproduction of the existing biomass.

In general, microbially degraded petroleum constituents are either oxidized all the way to CO₂ and H₂O or are used to build new biomass. In the former process, groundwater nutrient concentrations are unaffected. In the latter process, nutrients are removed from the groundwater and incorporated into new biomass at a rate which is approximately five pounds of nitrogen and one pound of phosphorous for each 100 pounds of carbon. If only the latter process existed, nutrient dosing would be a quasi-stoichiometric exercise dependant only on estimating the total mass of contaminants present. Induced, in some remedial situations, nutrient dosing is estimated using this assumption because it is "conservative"; actual nutrient needs will necessarily be lower.

Nutrient overdosing must be avoided for two reasons. High nutrient concentrations can cause osmotic shock, and when extreme, even death in the microbial mass. Also, nutrients are in some senses pollutants themselves, particularly, nitrogen in the form of nitrate. Nitrate-nitrogen concentrations must be kept below 10 mg/l (the MCL) primarily because (much) higher concentrations can cause neonatal methemoglobinemia. Nutrient overdosing is avoided by maintaining groundwater concentrations at levels lower than those thought to cause risk. Shallow groundwater nutrient concentrations will not be allowed to exceed 10 mg/l as nitrogen or 1 mg/l as phosphorous.

Nutrient concentrations above about 10% of these maxima will be more than sufficient to support microbial growth. Microbial cell membranes contain active transport mechanisms that allow scavenging nutrients from the environment when nutrients are present in still lower concentrations.

Prior to and throughout the landfarming process, shallow groundwater nutrient concentrations will be assayed. Common landscaping fertilizers will be added to the ground to make up nutrient deficits when necessary. When remediation is complete, the microbial mass will shrink (die) releasing nutrients to the groundwater. Released phosphorous is mineralized and becomes part of the soil. Released nitrogen in the form of NO_3 ions is reduced by denitrifying bacteria to N_2 , the principal component of air. Hence, residual nutrient contamination will not occur.

The third key to biostimulation - keeping the biomass in contact with contaminants to be degraded - is accomplished by mixing. Variations in the distribution of contaminants, nutrients, microbes and so forth result in several types of conditions which are less than optimal. Areas of very high contaminant concentrations can be toxic to soil organisms or so oily that water becomes the limiting "nutrient". Degradation will be completed in some areas sooner than others, leaving available microbes far from remaining contaminants in need of degradation.

Plowing is the principle mixing mechanism planned for this alternative. Initially, a backhoe will be used to turn over the upper four feet of soil. This provides vertical mixing and creates pathways for microbes and nutrients to reach levels not touched directly by plowing. The backhoe will also be used to micro-manage the distribution of contaminants. Hot spots, if found, will be spread out so they will decompose more quickly.

In sum, landfarming at DFSP would consist of the following steps:

- Determine the boundaries of the area to be remediated (test pits and assays);
- Remove existing berms and concrete pads (part of existing construction plans unrelated to this remediation);
- Berm the area to be remediated;
- Install wells to expand monitoring network;
- Assay shallow groundwater for nutrients;
- Apply sufficient fertilizer to the contaminated area to bring groundwater concentrations to target levels;
- Turn upper four feet of soils in the contaminated area and spread hot spots using a backhoe;
- Plow as frequently as practible;
- Periodically assay shallow groundwater for nutrients and augment as necessary;

- Periodically assay soils for progress; and
- Continue treatment as necessary.

3.2.2.3 Subsurface Biotreatment The subsurface biotreatment option involves the cycling of shallow groundwaters through an above-ground treatment system and addition of nutrients and oxygen to subsoils and groundwater (four to eight feet below grade). Nutrients would be introduced into the subsurface via the return flow of treated waters through infiltration trenches. Vacuum trenches would be installed and operated to pull air through the contaminated media. Groundwater would be withdrawn from beneath the site through a series of extraction wells and/or trenches. Groundwater would be pumped to an aerobic bioreactor. The reactor performs several functions. It provides a convenient place for metering nutrients into the stream, for saturating the stream with oxygen through aeration, and for rapidly culturing microbes capable of utilizing waste constituents as a carbon source and energy source. A monitoring program consisting of periodic sampling and laboratory analysis of soil and groundwater beneath the site should be initiated if the subsurface biotreatment alternative is implemented. This program would monitor the effectiveness of the remediation and would indicate whether there is a need for adjusting nutrient concentrations. Sampling and analytical costs associated with this alternative are estimated to be approximately \$7,000.

3.3 EVALUATION OF ALTERNATIVES This section evaluates the effectiveness, implementability, and cost effectiveness of the above mentioned in situ and ex situ remediation alternatives. The recommended remediation alternative and the recommended monitoring and sampling plans are also discussed.

3.3.1 Effectiveness and Implementability Each of the alternatives could be effectively applied to remediate the releases at DFSP. The time each would take to achieve clean-up goals varies. Excavation and landfilling is the most rapid and could be accomplished in several weeks. Thermal treatment is estimated to require three to four months. Any of the biological treatment options might be completed in three or four months, but could take two or three times that long. Insufficient data is available to accurately predict biodegradation rates. Although the no action alternative is essentially a biodegradation method, it would require much more time than the active biological methods. How much more is largely speculative.

Treatment time has special significance at DFSP. The Shipyard currently has a critical shortage of fuel storage capacity. Without the construction of additional capacity soon, planned expansion of the Shipyard's mission will not be possible. Because of the existing infrastructure, construction of additional capacity is only feasible at DFSP. Ideally, remediation will be complete at DFSP before construction begins. Consequently, in terms of timeliness alone, the landfilling option is preferred.

However, modifications to the other alternatives could be made which would make them compatible with the Navy's time requirements. The other ex situ alternatives could be speeded up by bringing in clean fill rather than waiting for removed soils to become sufficiently remediated for replacement in the pit. This would involve some increase in costs. Subsurface biotreatment could be designed to function in the presence of new tank construction without substantial cost increases. Landfarming, on the other hand, cannot be conducted once new tanks are built and would have to be terminated. Termination of landfarming prior to completion of remediation would involve switching to subsurface biotreatment until goals are achieved.

Effectiveness has another dimension beyond removal of contamination from DFSP. National policy is to completely destroy contaminants whenever it can be reasonably accomplished rather than merely transferring them to a new location or medium. All of the alternatives are effective on this criterion except the landfilling alternative.

The implementability of the various alternatives is nearly the same. We know of no institutional or regulatory constraints which would militate against any alternative other than the no action alternative. DHEC's proactive remediation policies appear to preclude implementation of the no action alternative.

3.3.2 Cost The ex situ alternatives all begin with excavation, staging, and dewatering of contaminated soils. These activities are estimated to cost \$2.50 to \$3.50 per (cubic) yard of soil removed [17.5K to 24.5K]*. Loading and transport of dewatered soils to the landfill at Pinewood, South Carolina are estimated to cost approximately \$25 per yard [175K]*. Disposal fees at the landfill should be near \$125 per yard [875K]*. Purchase and placement of clean fill in the pit are estimated at \$10 per yard [70K]*. Total groundwater treatment and disposal costs are estimated at \$3,000. Total sampling and analysis costs are estimated at \$5,000. If 7,000 cubic yards of contaminated soils are handled under this alternative, the total estimated cost will be approximately \$1,145,500 to \$1,152,500, exclusive of engineering, supervision, and other miscellaneous charges.

Transport and material handling costs for moving dewatered soils to an on-site thermal treatment unit or biological treatment cell are estimated at \$10 per yard [70K]*. Thermal

*Cost in thousands of dollars, based on handling an estimated 7,000 cubic yards of contaminated soils.

treatment costs should be in the range of \$40 to \$70 per yard [280K to 490K]*, while ex situ biological treatment is estimated at \$30 to \$45 per yard [210K to 320K]*. The cost of returning treated soils to the pit at the completion of remediation is also estimated to cost \$10 per yard [70K]. Total groundwater treatment and disposal costs are estimated at \$3,000. Total sampling and analysis costs are estimated at \$5,000. If 7,000 cubic yards of contaminated soils are handled under the thermal treatment alternative, the total estimated cost will be approximately \$447,500 to \$664,500. The ex situ biotreatment alternative costs are estimated to range between \$337,500 and \$444,500 for treatment of 7,000 yards of contaminated soils. These costs do not include engineering, supervision, and other miscellaneous charges.

The no action alternative carries no costs other than those associated with monitoring well installation, sampling, and laboratory analysis. Total monitoring well installation costs are estimated at \$8,000. Total sampling and laboratory analysis costs are estimated at \$20,000. If this alternative is selected, the total estimated cost will be approximately \$28,000.

Landfarming is a relatively inexpensive alternative with costs estimated at \$15 to \$20 per yard [105K to 140K]*. Total monitoring well installation costs are estimated at \$8,000. Total sampling and laboratory costs are estimated at \$10,000. If 7,000 yards of contaminated soils are remediated under this alternative, the total cost will be \$123,000 to \$158,000, exclusive of engineering, supervision, and other miscellaneous charges.

Subsurface biotreatment costs should be very close to ex situ biotreatment costs minus the costs of excavation, i.e., \$30 to \$45 per yard [210K to 315K]*. Total monitoring well installation costs are estimated at \$8,000. Total sampling and laboratory costs are estimated at \$7,000. If 7,000

*Cost in thousands of dollars, based on handling an estimated 7,000 cubic yards of contaminated soils.

yards of contaminated soils are remediated under this alternative, the total estimated cost will be \$225,000 to \$330,000, exclusive of engineering, supervision, and other miscellaneous charges.

A matrix showing estimated incremental and total costs of each ex situ remediation alternative is presented in Table 3-1.

In sum, landfarming is the least costly alternative, other than the no action alternative.

KEMRON obtained the price estimates outlined in the above paragraphs through correspondence with construction contracting and remedial contracting firms experienced in the appropriate areas after appraising them of conditions at DFSP. Contaminated soil handling prices, including excavation, staging, dewatering, loading, transportation, and backfill were obtained from Mr. Bill Perkins of Fenn-Vac, Inc. Fenn-Vac is a hazardous waste consulting firm specializing in the removal and transport of contaminated media and having experience in the Charleston area.

In situ and ex situ biotreatment estimates were obtained from Mr. John Opsasnick, Manager of Environmental Services for Sybron Chemicals, Inc. Sybron is an established, well respected firm which has designed and implemented dozens of bioremediation projects involving petroleum contaminated media.

Thermal treatment estimates were obtained from Mr. George Chedsey, Engineer and partner in ownership of the Soil Remediation Company (SRC). SRC is an established thermal remediation firm specializing in the treatment of petroleum contaminated soils.

Table 3-1. Summary Cost* Matrix (in thousands of dollars).

	<u>Landfill</u>	<u>Thermal</u>	<u>Bio-Cell</u>	<u>No Action</u>	<u>Landfarming</u>	<u>Subsurface Bio</u>
<i>Excavation, Staging & Dewatering</i>	17.5 to 24.5	17.5 to 24.5	17.5 to 24.5	na	na	na
<i>Treatment</i>	na	280 to 490	210 to 320	na	105 to 140	210 to 315
<i>Loading & Transportation</i>	175	70	70	na	na	na
<i>Disposal</i>	875	na	na	na	na	na
<i>Fill Dirt & Grading</i>	70	70	70	na	na	na
<i>Groundwater Treatment & Disposal</i>	3	3	3	na	na	na
<i>Monitoring Well Installation</i>	na	na	na	8	8	8
<i>Sampling & Analysis</i>	5	7	7	20	10	7
Total	1145.5 to 1152.5	447.5 to 664.5	377.5 to 494.5	28	123 to 158	225 to 330

* Assumes 7,000 cu. yd. of contaminated soil.

3-18

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30-Dec-1993 04:53:28am

The price estimates obtained from Fenn-Vac, Sybron, and SRC were compared with those listed in the following USEPA guidance documents:

Cost Estimates for Closure and Post-Closure Plans, Volume 1, November 1986;

Cost Estimates for Closure and Post-Closure Plans, Volume 4, November 1986; and

Compendium of Costs and Remedial Technologies at Hazardous Waste Sites, October 1987.

These estimates were found to be comparable to the price ranges presented in the above mentioned USEPA documentation.

3.3.3 Recommended Alternative We recommend that the in situ landfarming/ biostimulation alternative be implemented at this site. This recommendation is based on an evaluation of the trade-offs between cost and effectiveness, as shown on Table 3-2. Landfarming is the lowest cost implementable alternative. On the other hand, it may not achieve remediation goals within a sufficiently short time frame. The weight to be given this drawback-potential short-term failure is the key to evaluation of this alternative. Ultimately, whether landfarming or some other alternative is best depends on two factors: 1) the chance that landfarming may not achieve complete remediation within a suitably short time frame, and 2) the consequences that failure would entail.

Our professional opinion is that landfarming has an excellent chance of achieving clean-up goals within several months. This is based on favorable site factors, our experience with other

Table 3-2. Summary Evaluation Matrix

	<u>Effectiveness</u>	<u>Implementability</u>	<u>Cost (in thousands)*</u>
<i>Landfill</i>	Yes at DFSP, but does not destroy contaminants.	Yes.	\$1,146 to \$1,153
<i>Thermal</i>	Yes.	Yes.	\$448 to \$665
<i>Bio-Cell</i>	Yes.	Yes.	\$378 to \$495
<i>No Action</i>	Yes, but in an unrealistic time-frame.	Not permissible under current DHEC policies.	\$28
<i>Landfarming</i>	Yes, but perhaps not in sufficient time to meet short-term construction needs.	Yes.	\$123 to \$158
<i>Subsurface Bio</i>	Yes.	Yes.	\$225 to \$330

* Assumes 7,000 cu. yd. of contaminated soils.

3-20

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petroleum releases in the near-surface environment and our conversations with firms specializing in the bioremediation market.

In sum, landfarming is very favorable in terms of cost, is likely to be effective within the short timeframe required by the Navy's tank farm construction needs and is implementable. The risk that remediation will not be complete in time is modest because a back-up plan consisting of the second most economical alternative can be implemented if necessary. The back-up alternative is well-demonstrated, effective, and implementable.

Consequences of short term failure can be mitigated with contingency planning. A series of piped trenches will be installed beneath and prior to construction of the new concrete pad (current location of pad G). The piped trenches will be installed beneath the new tank in the eventuality that implementation of the contingency remediation plan becomes necessary. The trenches will be gravel filled and will house slotted schedule 80 PVC piping. The pipelines will extend beneath the entirety of the new concrete base pad, as illustrated in Figure 3-1. The terminal ends of each trench, located approximately five feet beyond the periphery of the new concrete pad will be sealed off beneath the ground surface until such time as implementation of the contingency plan may become a reality. Analytical results of soil and groundwater samples retrieved from beneath pad G prior to new tank construction, will determine the status of remedial activities. If nutrient injection beneath pad G, prior to its removal, and landfarming activities upon pad removal fail to successfully remediate the contaminated media to within acceptable levels, the primary remediation plan will be abandoned in favor of the in situ subsurface biotreatment plan, as described in paragraph 3.2.3.3. The termination points of each

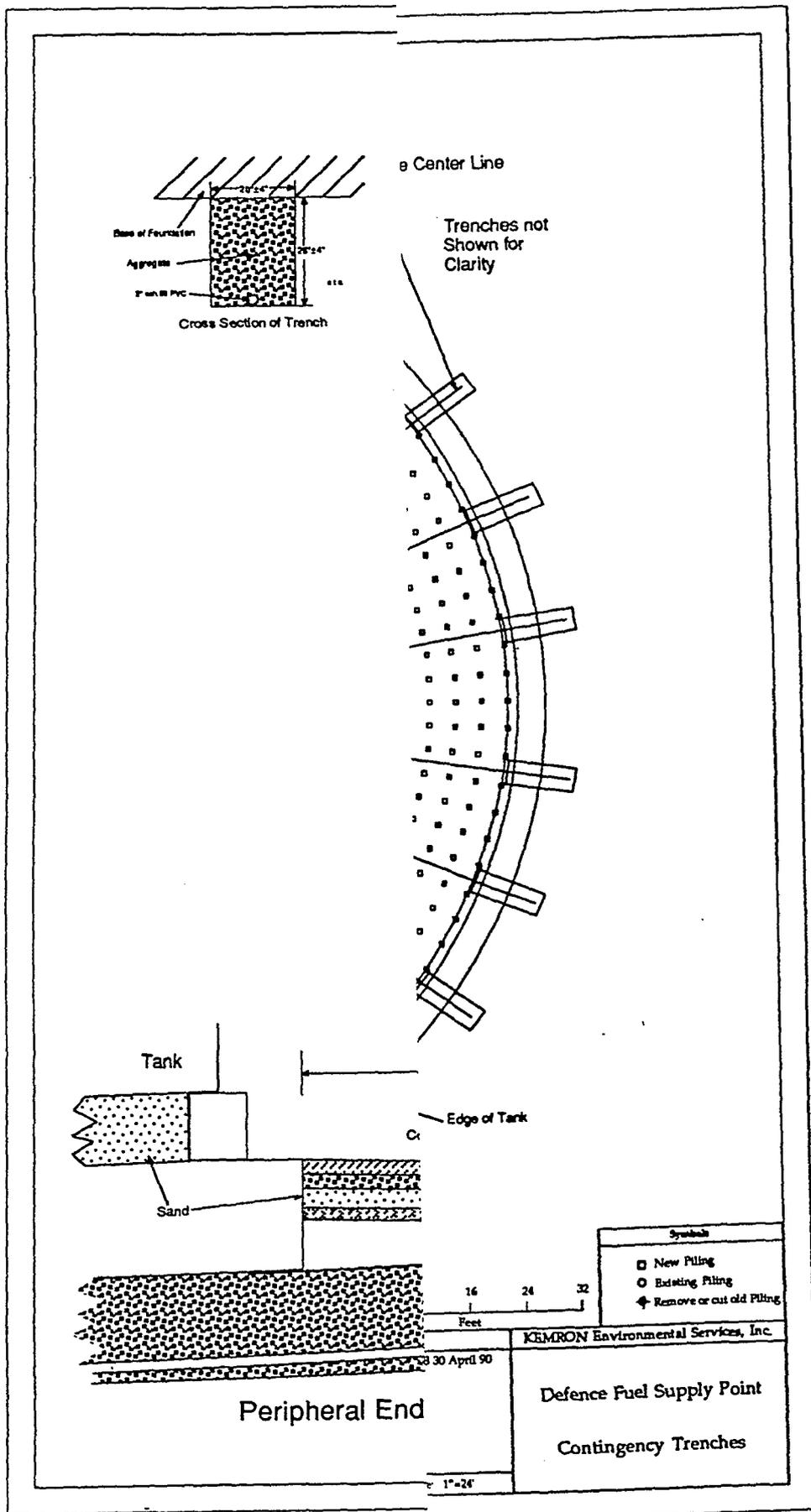


Figure 3-1. Defense Fuel Supply Po

pipeline trench, located at the margins of the new tank pad, will be unearthed upon completion of tank construction, if the contingency plan is activated. A circulating biotreatment system would then be constructed. The pipelines and trenches beneath the new pad will then be merged into the biotreatment system and will serve as essential nutrient injection galleries, groundwater extraction trenches, and vacuum trenches. Site remediation will subsequently be completed with the new tank in place.

Plowing will not be possible beneath the pad left behind by the dismantling of tank G. Under Navy contracting procedures, this pad cannot be removed until late in 1990. Remediation will be attempted with the pad in place by piping air and nutrients through it. Because conditions beneath the pad may have been anaerobic for decades, and as a result, microbes capable of aerobic decomposition may be absent, a small amount of dirt known to contain active microbes will be mixed with the nutrient solution to supply an inoculum.

What this system will accomplish is somewhat speculative. While biotreatment systems have been successfully operated beneath structure where a vadose zone existed, we are aware of none which has been attempted where the bottom of the structure lay in saturated soils.

The subpad treatment system will be constructed by coring through the pad in a grid pattern on 12 foot centers (to systematically miss the existing pilings which are on four foot centers). Forty-four cores will be made. A soil sample will be collected from the upper soil horizon, through each core hole using a hand auger. Samples from each quadrant will be composited; the four composites will be assayed for TPH, BTEX, and PAH. Air and nutrient addition lines

will be piped to and sealed in each core hole. The air lines will be grouped in pairs, valved, and manifolded to a blower.

Operation of the subpad system will begin with addition of approximately 20 gallons of nutrient solution through each core hole. The nutrient solution will contain 10 mg/l of ammonia plus nitrate nitrogen and 1 mg/l of phosphate phosphorous. It will also contain a small amount of inoculum as noted above. The nutrient addition ports will then be capped.

Aeration will be conducted using a programmable controller to open the valve to a single pair of air lines for a timed interval and then to each other pair of air lines in a programmed sequence. The cycle will then repeat.

When the pad is decommissioned, sampling will be conducted to determine whether further remedial efforts are necessary. Composites of the four quadrants will be collected (using EPA SW-846 protocols) and assayed for TPH, BTEX, and PAH.

3.3.4 Recommended Monitoring and Sampling The purposes of monitoring and sampling during the remediation and immediate post-remediation periods are several. The progress of the remediation towards goals must be monitored in order to judge when the work is complete, or, in a worst case, that it has failed. During remediation, nitrogen and phosphorous levels must be monitored in order to maintain sufficient nutrient availability to promote biodegradation and yet keep nutrient levels below those which might adversely impact groundwater quality.

The soil berms surrounding base pads G, H, and J will be partially removed prior to initiation of remediation activities, from areas where underlying petroleum contamination is presumed to be present. Soil samples will be randomly retrieved from the soil berm, as it is being removed, and shipped to the laboratory for analysis to determine if petroleum contamination is present. Ten TPH and BTEX assays will be conducted. Test pits will subsequently be excavated in locations around pads G, H, and J to finely delineate the petroleum contaminated interval beneath the site. Test pits will also be excavated in the ditch located west of pad J (Figure 2-1). ESE retrieved surface water and surface sediment samples from three locations in the ditch during their 1986 investigation. The surface water and surface sediment samples were assayed for BTEX, TPH, chlorobenzene, and total dichlorobenzene. Surface water assays reportedly revealed no detections of the above mentioned constituents. Surface sediment assays reportedly found only TPH concentrations ranging from 43.9 to 268 ppm. Test pits will be excavated in the ditch to determine the extent, if any, of petroleum contamination in the soils beneath the ditch.

Upon excavation of each test pit, visual observations and soil characteristics (i.e., odor, texture, type, etc.) will be recorded in a field log book. Head space assays will be performed on multiple soil samples from each pit. The head space assay will be initiated by sealing a soil sample retrieved from the test pit into a plastic zip-lock baggie. The sample will then be allotted a specific period of time during which volatilization of any contaminants should occur. Field organic vapor detection instruments, specifically a photoionization detector (PID), and an organic vapor analyzer (OVA) will then be inserted into the sealed baggie to obtain a reading of volatilized organic compounds. Field instrumentation readings will be recorded in a field log book.

Soil samples will be retrieved from 20 of the above mentioned test pits and shipped to the laboratory for analysis. Selection of test pits to be sampled for laboratory analysis will be based on field instrumentation and olfactory detection. Samples retrieved from test pits located near the fringe of petroleum contamination, as determined in the field, will be selected for laboratory analysis. TPH, BTEX, and PAH assays will be performed on samples retrieved from each of the 20 test pits.

Nearby groundwater will also be monitored in order to detect potential migration of petroleum contaminants, or to detect adverse impacts from the biodegradational nutrients, if any, before they spread too far to be controlled. Eight additional monitoring wells will be installed at the site for this purpose. Proposed monitoring well locations in relation to existing monitoring wells are shown in Figure 3-2. These eight groundwater monitoring wells will be installed by a South Carolina certified drilling contractor prior to initiation of remediation. The monitoring wells will be advanced to a depth approximately seven feet below the existing water table. Borings will be advanced by a truck mounted drill rig using 6 1/4-inch O.D. hollow stem augers. Cuttings and soil samples retrieved from each borehole will be monitored in the field with a PID for organic vapors. Soil sampling will be performed in accordance with ASTM D 1586. A standard 1.4-inch I.D., 2-inch O.D., split barrel stainless steel sampler will be used. The sampler will be first seated six inches into the ground to penetrate loose cuttings, and subsequently driven an additional foot with blows from a 140-pound hammer falling 30 inches. The number of blows required to drive the sampler the final foot will be recorded. Soils, when removed from the sampler, will be inspected for soil characteristics, which will be recorded on borehole-specific logs. All equipment coming in contact with the soil will be decontaminated by steam cleaning between boreholes.

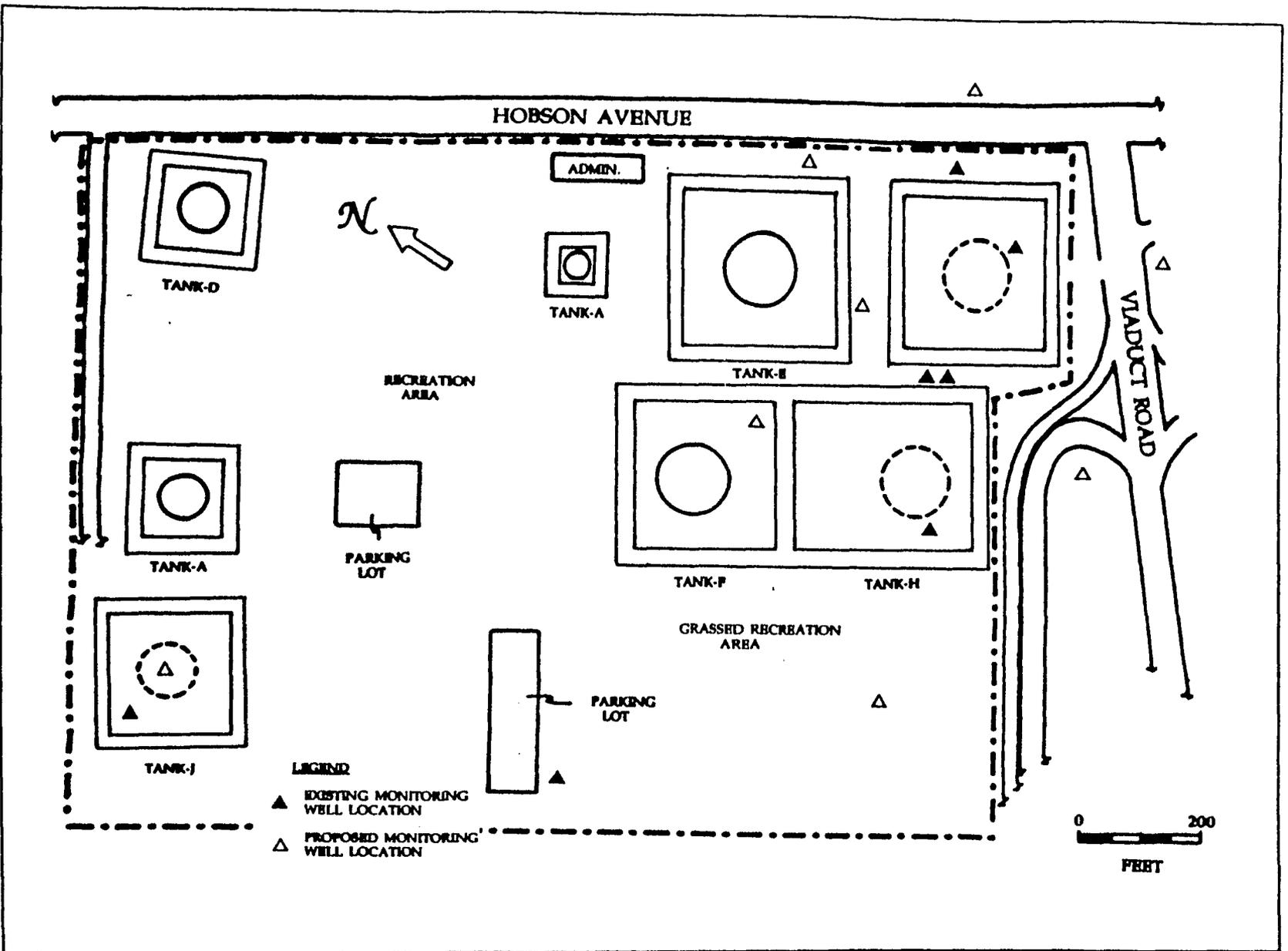


Figure 3-2. Proposed monitoring well locations.

Monitoring wells will be installed in each of the soil borings described above. Initially, auger flights used to drill each borehole will remain in place to prevent the boring walls from collapsing. Two-inch diameter schedule 40 PVC screen and riser pipe will be installed into each borehole. Approximately ten feet of screen with 0.01 inch slots will be placed into each borehole such that approximately three feet will extend above and seven feet will extend below the groundwater table at the time of drilling (screen and riser lengths may be adjusted if an unexpectedly high or low water table is encountered). Riser pipe will be added to the screen section to set each well approximately three feet above the ground surface. A tremie pipe will be used to backfill the annular space adjacent to the screen section with a sand pack. The augers will be pulled up as sand is tremied into the annular space. This sand pack will extend approximately two feet above the screened interval. The one foot annular space interval directly above the sand pack will be filled with bentonite pellets and water to form an expansive seal. A 5% bentonite grout will be sequentially tremied into the annular space extending from the top of the bentonite seal to one foot below the ground surface. Quantities and depths of sand and bentonite fill may be smaller if the water table is extremely high. Portland cement will be poured into the annular space and filled to approximately six inches below grade. A cement pad, extending to a depth of six inches below grade and six inches beyond the borehole diameter will be installed around each well. The cement pad will serve to prevent infiltration between the surface casing and the borehole. Stick-up protective casings will be placed over each well as an added security measure. The wells will be completed with a locking plastic cap placed on the riser pipe. A cross-sectional diagram, showing the proposed monitoring well construction details, is presented in Figure 3-3.

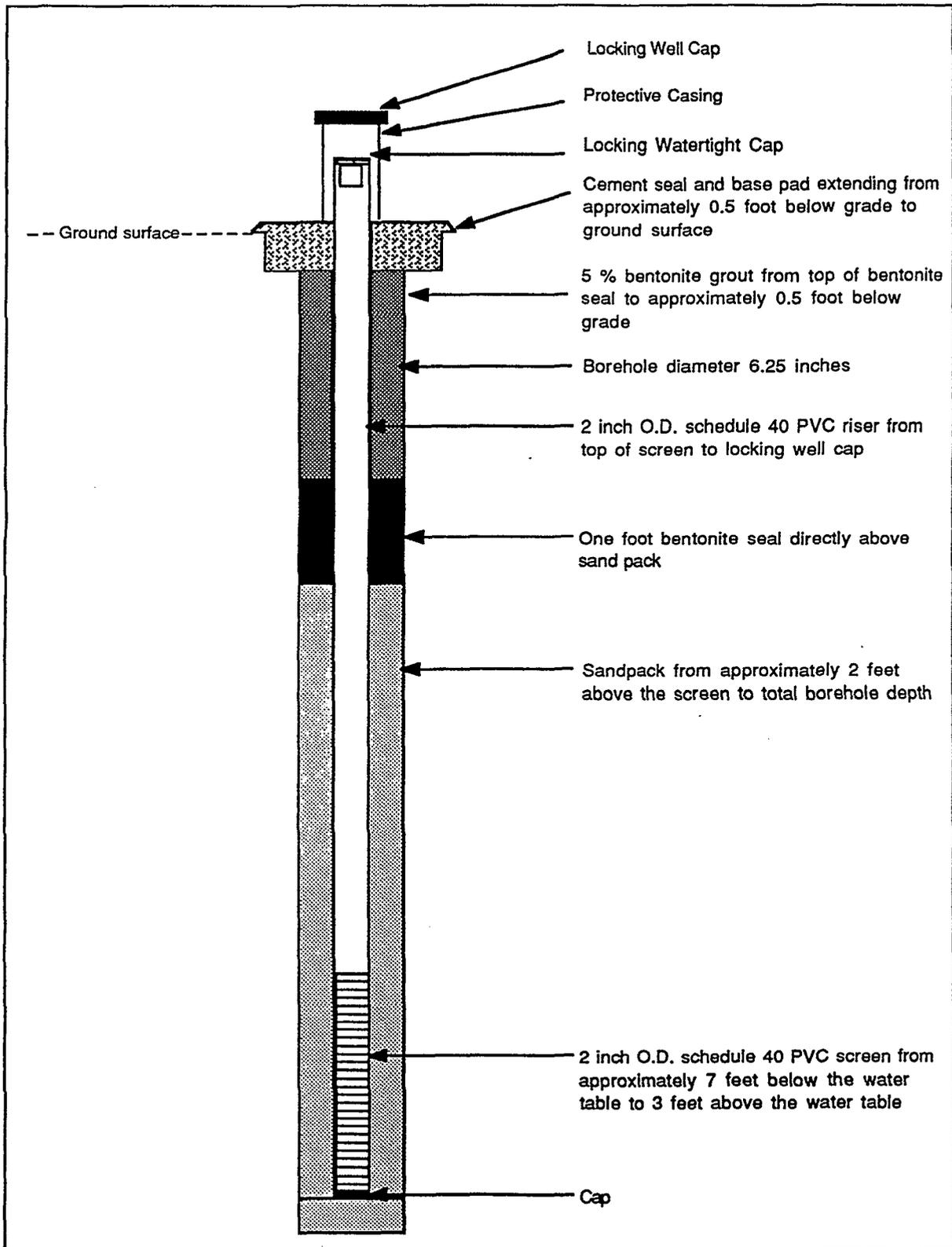


Figure 3-3. Proposed monitoring well schematic

Each of the eight monitoring wells will be sampled monthly for six months, followed by quarterly sampling for two years. All groundwater samples retrieved from these wells will be assayed for nitrogen, phosphorous, petroleum hydrocarbons, pH and total organic carbon. Slug tests will be performed on four of these monitoring wells upon their installation, development, and sampling. Shallow groundwaters in the treatment zone will be sampled weekly for a period of four months. The contaminated interval will be subdivided into five zones. A groundwater sample will be retrieved from a random location within each zone during each sampling episode. Each sample will be assayed for nitrogen, phosphorous, TPH, pH, and total organic carbon. A groundwater sample retrieved from one of the five zones during each sampling episode will be assayed for TPH. The shallow soil horizon within the till zone will also be sampled weekly, and will be assayed for nitrogen, phosphorous, pH, and total organic carbon. A soil sample retrieved from one of the five zones as listed above, during each sampling episode will be assayed for TPH. Potentially contaminated soil horizons beneath the till zone will also be sampled periodically, though not necessarily as frequently as other soils, and will also be assayed for petroleum hydrocarbons.

Aquifer tests will be conducted on four monitoring wells installed during this investigation to determine hydraulic conductivity, and flow rates of the near surface aquifer in the immediate vicinity of the wells tested. The tests will be performed by pouring a specific amount of tap water into each well, raising the water elevation to the top of the riser pipe, or by bailing groundwater out of each well, lowering the elevation to the bottom of the screened interval. The rising or falling water elevations with the wells will be closely monitored and recorded until recovery is complete. Recovery will be considered complete when water levels within the wells stabilize near pre-test values.

Hydraulic conductivity values will be calculated using the recovery rate and construction data from each well. Analyses will be performed utilizing the methods of Hvorslev (1951) and Bouwer and Rice (1976).

Aquifer flow rates will be calculated using the following equation derived from Davey's Law:

$$V=Ki/n$$

Where V = the aquifer flow rate in ft/sec
 K = the hydraulic conductivity in ft/sec
 i = the hydraulic gradient
 n = the effective porosity of the aquifer

Flow rates will be calculated using well specific hydraulic conductivity values, estimated values of hydraulic gradient, and estimated effective porosity.

CHAPTER 4. REFERENCES

30-Dec-1993 04:53:55am

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30-Dec-1993 04:53:59 am

APPENDIX A
ESE LABORATORY RESULTS

0016285

Table 5.1-1 Analytical Results for Soil Samples (Page 1 of 2)

Parameter	Units	Method	Detection Limits *	SB-1	SB-2	SB-3	SB-4	SB-5	SB-6	SB-7
Moisture	% Wet Wt.	70320	-	18.9	60.6	7.0	13.1	15.3	16.6	1.2
TRPH	mg/kg (ppm)	98233	33.7 - 35.3	7280	146	1370	979	510	9010	249
Benzene	µg/kg (ppb)	34237	84.1 - 200	<102	<200	<89.4	<95.9	<98.4	<99.4	<84.1
Chlorobenzene	µg/kg (ppb)	34304	84.1 - 200	<102	<200	<89.4	<95.9	<98.4	<99.4	<84.1
Dichlorobenzene, Total	µg/kg (ppb)	98578	84.1 - 200	<102	<200	<89.4	<95.9	<98.4	<99.4	<84.1
Ethylbenzene	µg/kg (ppb)	34374	84.1 - 200	<102	<200	<89.4	<95.9	<98.4	<99.4	<84.1
Toluene	µg/kg (ppb)	34483	84.1 - 200	<102	<200	<89.4	<95.9	<98.4	<99.4	<84.1
Xylenes, Total	µg/kg (ppb)	45510	84.1 - 200	<102	<200	<89.4	<95.9	<98.4	<99.4	<84.1

Source: ESE 1986

Note: mg/kg = Milligram per kilogram
µg/kg = Micrograms per kilogram

* Detection limits vary according to soil moisture content

5-2

0016286

30-Dec-1993 04:54:01am

Table 5.1-1 Analytical Results for Soil Samples (Page 1 of 2)

Parameter	Units	Method	Detection Limits *	SB-8	SB-9	SB-10	SB-11	SB-12	SB-13	SB-14	SB-15
Moisture	% Wet Wt.	70320	-	22.2	18.5	24.0	28.7	25.0	22.7	15.7	28.0
TRPH	mg/kg (ppm)	98233	33.7 - 35.3	<35.3	<33.7	1050	39.5	55.9	2470	238	121
Benzene	µg/kg (ppb)	34237	84.1 - 200	<106	<102	<109	<117	<111	<107	<98.4	<115
Chlorobenzene	µg/kg (ppb)	34304	84.1 - 200	<106	<102	<109	<117	<111	<107	<98.4	<115
Dichlorobenzene, Total	µg/kg (ppb)	98578	84.1 - 200	<106	<102	<109	<117	<111	<107	<98.4	<115
Ethylbenzene	µg/kg (ppb)	34374	84.1 - 200	<106	<102	<109	<117	<111	<107	<98.4	<115
Toluene	µg/kg (ppb)	34483	84.1 - 200	<106	<102	<109	<117	<111	<107	<98.4	<115
Xylenes, Total	µg/kg (ppb)	45510	84.1 - 200	<106	<102	<109	<117	<111	<107	<98.4	<115

Source: ESE 1986

Note: mg/kg = Milligram per kilogram
µg/kg = Micrograms per kilogram

* Detection limits vary according to soil moisture content

5-3

0016287

30-Dec-1993 04:54:03 am

Table 5.1-2 Analytical Results for Ground Water Samples Sampled on August 11, 1986

Parameter	Units	Method	Detection Limits	CSC-3900-1	CSC-3900-2	CSC-3900-3D	CSC-3900-3S	CSC-3900G-1	CSC-3900H-1	CSC-39J-1
pH	S.U.	Field	-	7.1	7.9	7.6	7.8	8.0	7.7	7.7
Temperature	°C	Field	-	23.6	23.0	22.0	26.3	26.5	27.2	21.1
Conductivity	µmhos/cm	Field	-	12,600	38,500	24,300	22,200	5,320	3,800	31,200
TRPH	µg/l	45501	183 - 194	<190	<194	<190	130,000	2,850	341	<183
Benzene	µg/l	3403D	1.00	<1.00	<1.00	<1.00	1.23	<1.00	<1.00	<1.00
Chlorobenzene	µg/l	34301	1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
Dichlorobenzene, Total	µg/l	81524	1.00 - 3.00	<3.00	<3.00	<3.00	<3.00	<3.00	<1.00	<1.00
Ethylbenzene	µg/l	34371	1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
Toluene	µg/l	34010	3.00	<3.00	<3.00	<3.00	<3.00	<3.00	<3.00	<3.00
Xylenes, Total	µg/l	81551	1.00 - 3.00	<3.00	<3.00	<3.00	<3.00	<3.00	<1.00	<1.00

Source: ESE 1986

Note: S.U. = Standard Units
µmhos/cm = Micromhos per centimeter
µg/l = Micrograms per liter

0016288

30-Dec-1993 04:54:04am

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04:54:06am

Table 5.1-3 Analytical Results for Surface Water Samples

Parameter	Units	Method	Detection Limits	SW-1	SW-2	SW-3
pH	S.U.	Field	-	7.1	7.4	6.5
Temperature	°C	Field	-	29.4	28.5	27.7
Conductivity	µmhos/cm	Field	-	26,000	27,900	26,700
TRPH	µg/l	45501	184 - 190	<184	<190	<188
Benzene	µg/l	34030	1.0	<1.00	<1.00	<1.00
Chlorobenzene	µg/l	34301	1.0	<1.00	<1.00	<1.00
Dichlorobenzene, Total	µg/l	81524	1.0	<1.00	<1.00	<1.00
Ethylbenzene	µg/l	34371	1.0	<1.00	<1.00	<1.00
Toluene	µg/l	34010	3.0	<3.00	<3.00	<3.00
Xylenes, Total	µg/l	81551	1.0	<1.00	<1.00	<1.00

Source: ESE 1986

Note: S.U. = Standard Units

µmhos/cm = Micromhos per centimeter

µg/l = micrograms per liter

34-Dec-1993 04:54:07am

Table 5.1-4 Analytical Results for Sediment Samples

Parameter	Units	Method	Detection Limits	SE-1	SE-2	SE-3
Moisture	% Wet Wt.	70320	-	36.8	33.7	17.8
TRPH	mg/kg (ppm)	98233	35	135	268	43.9
Benzene	µg/kg (ppb)	34237	161 - 211	<211	<200	<161
Chlorobenzene	µg/kg (ppb)	34304	161 - 211	<211	<200	<161
Dichlorobenzene, Total	µg/kg (ppb)	98578	161 - 211	<211	<200	<161
Ethylbenzene	µg/kg (ppb)	34374	161 - 211	<211	<200	<161
Toluene	µg/kg (ppb)	34483	161 - 211	<211	<200	<161
Xylenes, Total	µg/kg (ppb)	45510	161 - 211	<211	<200	<161

Source: ESE 1986

Note: mg/kg = Milligram per kilogram
µg/kg = Micrograms per kilogram

Table 5.1-7 Analytical Results for Ground Water Samples Sampled on May 18 and 19, 1987

Parameter	Units	Detection Limits	Monitor Well No.						
			CSC-3900-1	CSC-3900-2	CSC-3900-3D	CSC-3900-3S	CSC-3900G-1	CSC-3900H-1	CSC-39J-1
Water Temp.	°C	-	23.2	21.8	22.6	22.5	21.6	23.1	22.1
pH, field	Std Uts	-	5.30	7.10	6.90	7.00	7.60	7.10	6.30
Sp. Cond. field @25°C	unhos/cm	-	9750	33500	24600	21000	5880	3050	25600
Petroleum Hydrocarbons	µg/l	217 - 260	<233	<222	6,680	9,410	<222	<217	<260
<u>PURGEABLE AROMATICS</u>									
Benzene	ug/l	10	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0
Toluene	ug/l	20	<20.0	<20.0	<20.0	<20.0	<20.0	<20.0	<20.0
Xylenes, Total	ug/l	3	<3.00	<3.00	<3.00	<3.00	<3.00	<3.00	<3.00
<u>POLYNUCLEAR AROMATIC HYDROCARBONS</u>									
Acenaphthene	ug/l	0.363	<0.363	<0.363	4.10	82.1	5.86	<0.363	<0.363
Acenaphthylene	ug/l	0.202	<0.202	0.377	<2.02	<10.1	15.2	<0.202	0.252
Anthracene	ug/l	0.023	<0.023	0.105	4.06	53.6	2.15	0.027	<0.023
Benzo(a)anthracene	ug/l	0.017 - 0.168	<0.017	0.035	5.37	16.1	<0.168	<0.017	0.019
Benzo(a)pyrene	ug/l	0.029	<0.029	<0.029	0.644	3.61	0.302	<0.029	0.031
Benzo(b)fluoranthene	ug/l	0.017	<0.017	<0.017	0.846	4.74	0.186	<0.017	<0.017
Benzo(ghi)perylene	ug/l	0.059 - 2.96	<0.059	<0.059	<0.593	<2.96	<0.593	<0.059	<0.059
Benzo(k)fluoranthene	ug/l	0.018 - 0.180	<0.018	<0.018	0.398	2.94	<0.180	<0.018	<0.018
Chrysene	ug/l	0.012	<0.012	<0.012	0.999	7.75	1.86	<0.012	<0.012
Diben(a,h)anthracene	ug/l	0.715 - 3.58	0.425	0.287	<0.715	<3.58	<0.715	0.287	0.383
Fluoranthene	ug/l	0.049	<0.049	0.331	13.0	123	6.01	0.107	0.061
Fluorene	ug/l	0.043	<0.043	3.34	2.71	38.3	6.53	<0.043	1.62
Indeno(1,2,3-cd)pyrene	ug/l	0.044 - 2.20	<0.044	<0.044	<0.440	<2.20	<0.440	<0.044	<0.044
Naphthalene	ug/l	0.156	<0.156	2.64	8.00	49.0	6.42	0.342	1.22
Phenanthrene	ug/l	0.156	0.178	3.06	17.1	1410	24.3	0.782	0.387
Pyrene	ug/l	0.048	<0.048	0.214	12.6	59.9	4.90	0.094	0.050
Total PAHs*	µg/l	-	0.6	10.4	69.8	1851.0	73.7	1.6	4.0

* Total PAHs include arithmetic summation of detected compounds only.

Source: ESE, 1987

30-Dec-1993 04:54:09am

5-15

0016291

30-Dec-1993 04:54:18 am

APPENDIX B
BORINGS LOGS

0016292

BORING LOGS

Conducted by: KEMRON Environmental Services

Date: 17-18 January 1990

38-Dec-1993 04:54:12am

Boring No.	Depth (ft)	Description
B-1	0 - 4	Silty clay, dark brown, no petroleum odor.
	4 - 10	Clayey sand, fine to coarse grain, red to tan to gray, no petroleum odor.
B-2	0 - 2	Silty clay, dark brown, no petroleum odor.
	2 - 6	Clayey sand, fine to coarse grain, no petroleum odor.
B-3	0 - 2	Sand, fine grain, no petroleum odor.
	2 - 5	Sandy clay, greenish gray, no petroleum odor.
	5 - 10	Clayey sand, fine to medium grain, greenish gray, no petroleum odor.
B-4	0 - 2	Clayey sand, fine to coarse grain, dark brown to gray, no petroleum odor.
	2 - 4	Sand, fine to medium grain, tan to brown, no petroleum odor.
	4 - 8	Clayey sand, fine to medium grain, iron staining, no petroleum odor.
B-5	0 - 5	Clay, dark brown, petroleum odor.
	5 - 6	Sandy clay, green to tan, no petroleum odor.
	6 - 8	Clayey sand, fine to medium grain, green to tan, iron staining, no petroleum odor.
	8 - 10	Clayey sand, fine grain, red, no petroleum odor.

BORING LOGS (continued).

30-Dec-1993 04:54:13am

Boring No.	Depth (ft)	Description
B-6	0 - 3	Sand, fine grain, red to tan, no petroleum odor.
	3 - 6	Clayey sand, fine to medium grain, dark brown to black, petroleum odor (oil film and small droplets visible in groundwater at 5 feet).
	6 - 10	Clay, black to dark gray, petroleum odor (high liquid percentage clay layer encountered from 7.5 feet to total borehole depth).
B-7	0 - 2	Sand, fine grain, grayish green to brown to black, petroleum odor, petroleum stain.
	2 - 3	Sandy clay, black, iron staining, no odor.
	3 - 4	Clay, black to dark gray, wood chips, no petroleum odor.
	4 - 8	Clayey sand, fine to medium grain, dark gray to dark brown, no petroleum odor.
	8 - 10	Sandy clay, black, petroleum odor.
B-8	0 - 2	Sandy clay, dark brown, no petroleum odor.
	2 - 6	Sandy silty clay, dark brown, no petroleum odor.
	6 - 8	Clay, green to dark gray, no petroleum odor.
	8 - 10	Sandy clay, dark brown to black to gray, no petroleum odor (high liquid percentage sandy clay interval encountered from 8 feet to total borehole depth).

0016294

BORING LOGS (concluded).

30-Dec-1993 04:54:15am

Boring No.	Depth (ft)	Description
B-9	0 - 1	Sand, fine to medium grain, brown, no petroleum odor.
	1 - 3	Sandy clay, dark gray to dark brown, petroleum odor.
	3 - 6	Clayey sand, fine to medium grain, dark brown to gray, petroleum odor.
	6 - 10	Sandy clay, dark brown to dark gray to black, no odor (high liquid percentage sandy clay interval encountered from 8 feet to total borehole depth).

30-Dec-1993 04:54:16am

APPENDIX C
KEMRON LABORATORY RESULTS

0016296

REPORT Wapora, Inc.
TO 1815 Century Blvd.
Suite 150
Atlanta, GA 30345
ATTEN John Dwyer
CLIENT WAPATL 59227 SAMPLES 23
COMPANY Wapora, Inc.
FACILITY Atlanta

PREPARED KEMRON ENVIRONMENTAL SERVICES
BY 109 STARLITE PARK
MARIETTA, OHIO 45750
ATTEN _____
PHONE (614) 373-4071

CERTIFIED BY

CONTACT H BUSKIRK

ALL WORK PERFORMED IN ACCORDANCE WITH STANDARD METHODOLOGY.

WORK ID 819-400/Navy-DFSP
TAKEN Client
TRANS Fed Ex
TYPE _____
P.O. # _____
INVOICE under separate cover

SAMPLE IDENTIFICATION

TEST CODES and NAMES used on this report

- 1 B11-8/10
- 2 B8-8/10
- 3 B11-4
- 4 B8-6
- 5 B8-2
- 6 B8-4
- 7 Trip Blank 1
- 3 B9-2
- 2 Trip Blank 2
- 0 Trip Blank
- 1 B9-4
- 2 B11-2P
- 3 B7-10
- 4 B7-4
- 5 B7-2
- 6 B7-6
- 7 B6-4
- 3 B6-5P
- 2 B7-8P
- 0 B6-2
- 1 B6-8/10

- M8100 Polyaromatic Hydrocarbons
- PCT S Percent Solids
- TPH S Petroleum Hydrocarbons

0016297

04:54:18am



Paç
Received: 19/90

KEMRON

REPORT

Work Order # NO-0113

02/02/90 15:17:58

SAMPLE IDENTIFICATION

22 B7-8

23 B6-6

0016298

04:54:19am
KEMRON
ENVIRONMENTAL SERVICES

age 3
Received: 01/19/90

KEMRON REPORT
Results by Sample

Work Order # NO-01113

SAMPLE ID B11-8/10 SAMPLE # 01 FRACTIONS: A
Date & Time Collected 01/18/90 15:45:00 Category SOLID

PCT_S 45 TPH_S <25
% wt. mg/kg

SAMPLE ID B8-8/10 SAMPLE # 02 FRACTIONS: A
Date & Time Collected 01/18/90 14:20:00 Category SOLID

PCT_S 45 TPH_S <25
% wt. mg/kg

SAMPLE ID B11-4 SAMPLE # 03 FRACTIONS: A
Date & Time Collected 01/18/90 15:30:00 Category SOLID

PCT_S 64 TPH_S <25
% wt. mg/kg

SAMPLE ID B8-6 SAMPLE # 04 FRACTIONS: A
Date & Time Collected 01/18/90 14:15:00 Category SOLID

PCT_S 46 TPH_S <25
% wt. mg/kg

SAMPLE ID B8-2 SAMPLE # 05 FRACTIONS: A
Date & Time Collected 01/18/90 14:05:00 Category SOLID

PCT_S 70 TPH_S <25
% wt. mg/kg

SAMPLE ID B8-4 SAMPLE # 06 FRACTIONS: A
Date & Time Collected 01/18/90 14:10:00 Category SOLID

PCT_S 64 TPH_S <25
% wt. mg/kg

04:54:21am

KEMRON
ENVIRONMENTAL SERVICES

0016299

Page -
Received: 01/19/90

KEMRON REPORT
Results by Sample

Work Order # NO-0113

SAMPLE ID Trip Blank 1 SAMPLE # 07 FRACTIONS: A
Date & Time Collected 01/18/90 13:00:00 Category SOLID
PCT_S * TPH_S <25
 % wt. mg/kg

SAMPLE ID B9-2 SAMPLE # 08 FRACTIONS: A
Date & Time Collected 01/18/90 15:05:00 Category SOLID
PCT_S 72 TPH_S 320
 % wt. mg/kg

SAMPLE ID Trip Blank 2 SAMPLE # 09 FRACTIONS: A
Date & Time Collected 01/18/90 13:00:00 Category SOLID
PCT_S 90 TPH_S 110
 % wt. mg/kg

SAMPLE ID Trip Blank SAMPLE # 10 FRACTIONS: A
Date & Time Collected 01/18/90 13:00:00 Category SOLID
PCT_S 97
 % wt.

0016300

04:54:27am

KEMRON
ENVIRONMENTAL SERVICES

SAMPLE ID Trip Blank FRACTION 10A TEST CODE M8100 NAME Polyaromatic Hydrocarbons
Date & Time Collected 01/18/90 13:00:00 Category SOLID

ANALYST: DDE EXTRACTED: 01/26/90 FILE #: 0129A09A
INSTRMT: HP_II INJECTED: 01/29/90 FACTOR: 33 UNITS: ug/kg

CAS#	COMPOUND	RESULT	DET LIMIT	VERIFIED: CLM
91-20-3	Naphthalene	BDL	30	
208-96-8	Acenaphthylene	BDL	30	
83-32-9	Acenaphthene	BDL	30	
86-73-7	Fluorene	BDL	30	
85-01-8	Phenanthrene	BDL	30	
120-12-7	Anthracene	BDL	30	
206-44-0	Fluoranthene	BDL	30	
129-00-0	Pyrene	BDL	30	
56-55-3	Benzo(a)anthracene	BDL	200	
218-01-9	Chrysene	BDL	200	
205-99-2	Benzo(b)fluoranthene	BDL	200	
207-08-9	Benzo(k)fluoranthene	BDL	200	
50-32-8	Benzo(a)pyrene	BDL	200	
193-39-5	Indeno(1,2,3-cd)pyrene	BDL	200	
53-70-3	Dibenzo(a,h)anthracene	BDL	200	
191-24-2	Benzo(g,h,i)perylene	BDL	200	

NOTES AND DEFINITIONS FOR THIS REPORT

DET LIMIT = DETECTION LIMIT
BDL = BELOW DETECTION LIMIT
NA = NOT ANALYZED
NF = NOT FOUND
DL = DILUTED OUT

0016301

04:54:24am

SAMPLE ID B9-4 SAMPLE # 11 FRACTIONS: A
Date & Time Collected 01/18/90 15:10:00 Category SOLID

PCT_S 67 TPH_S <25
% wt. mg/kg

SAMPLE ID B11-2P SAMPLE # 12 FRACTIONS: A
Date & Time Collected 01/18/90 15:25:00 Category SOLID

PCT_S 75 TPH_S 740
% wt. mg/kg

0016302

SAMPLE ID B11-2P FRACTION 12A TEST CODE M8100 NAME Polyaromatic Hydrocarbons
Date & Time Collected 01/18/90 15:25:00 Category SOLID

ANALYST: DDE EXTRACTED: 01/26/90 FILE #: 0129A16A
INSTRMT: HP_II INJECTED: 01/30/90 FACTOR: 33 UNITS: ug/kg

CAS#	COMPOUND	RESULT	DET LIMIT	VERIFIED: CLM
91-20-3	Naphthalene	BDL	30	
208-96-8	Acenaphthylene	1600	30	
83-32-9	Acenaphthene	1200	30	
86-73-7	Fluorene	870	30	
85-01-8	Phenanthrene	960	30	
120-12-7	Anthracene	670	30	
206-44-0	Fluoranthene	BDL	30	
129-00-0	Pyrene	BDL	30	
56-55-3	Benzo(a)anthracene	BDL	200	
218-01-9	Chrysene	BDL	200	
205-99-2	Benzo(b)fluoranthene	BDL	200	
207-08-9	Benzo(k)fluoranthene	BDL	200	
50-32-8	Benzo(a)pyrene	BDL	200	
193-39-5	Indeno(1,2,3-cd)pyrene	BDL	200	
53-70-3	Dibenzo(a,h)anthracene	BDL	200	
191-24-2	Benzo(g,h,i)perylene	BDL	200	

NOTES AND DEFINITIONS FOR THIS REPORT
DET LIMIT = DETECTION LIMIT
BDL = BELOW DETECTION LIMIT
NA = NOT ANALYZED
NF = NOT FOUND
DL = DILUTED OUT

0016303

04:54:27am

SAMPLE ID B7-10 SAMPLE # 13 FRACTIONS: A
Date & Time Collected 01/18/90 13:55:00 Category SOLID
PCT_S 44 TPH_S <25
% wt. mg/kg

SAMPLE ID B7-4 SAMPLE # 14 FRACTIONS: A
Date & Time Collected 01/18/90 13:40:00 Category SOLID
PCT_S 81 TPH_S <25
% wt. mg/kg

SAMPLE ID B7-2 SAMPLE # 15 FRACTIONS: A
Date & Time Collected 01/18/90 13:35:00 Category SOLID
PCT_S 95 TPH_S 32
% wt. mg/kg

SAMPLE ID B7-6 SAMPLE # 16 FRACTIONS: A
Date & Time Collected 01/18/90 13:45:00 Category SOLID
PCT_S 58 TPH_S 43
% wt. mg/kg

SAMPLE ID B6-4 SAMPLE # 17 FRACTIONS: A
Date & Time Collected 01/18/90 13:05:00 Category SOLID
PCT_S 83 TPH_S 3500
% wt. mg/kg

SAMPLE ID B6-5P SAMPLE # 18 FRACTIONS: A
Date & Time Collected 01/18/90 13:20:00 Category SOLID
PCT_S 59
% wt.

SAMPLE ID B6-5P FRACTION 18A TEST CODE M8100 NAME Polyaromatic Hydrocarbons
Date & Time Collected 01/18/90 13:20:00 Category SOLID

ANALYST: DDE EXTRACTED: 01/26/90 FILE #: 0129A12A
INSTRMT: HP_II INJECTED: 01/30/90 FACTOR: 33 UNITS: ug/kg

CAS#	COMPOUND	RESULT	DET LIMIT	VERIFIED: CLM
91-20-3	Naphthalene	BDL	30	
208-96-8	Acenaphthylene	BDL	30	
83-32-9	Acenaphthene	BDL	30	
86-73-7	Fluorene	BDL	30	
85-01-8	Phenanthrene	50	30	
120-12-7	Anthracene	BDL	30	
206-44-0	Fluoranthene	BDL	30	
129-00-0	Pyrene	BDL	30	
56-55-3	Benzo(a)anthracene	BDL	200	
218-01-9	Chrysene	BDL	200	
205-99-2	Benzo(b)fluoranthene	BDL	200	
207-08-9	Benzo(k)fluoranthene	BDL	200	
50-32-8	Benzo(a)pyrene	BDL	200	
193-39-5	Indeno(1,2,3-cd)pyrene	BDL	200	
53-70-3	Dibenzo(a,h)anthracene	BDL	200	
191-24-2	Benzo(g,h,i)perylene	BDL	200	

NOTES AND DEFINITIONS FOR THIS REPORT
DET LIMIT = DETECTION LIMIT
BDL = BELOW DETECTION LIMIT
NA = NOT ANALYZED
NF = NOT FOUND
DL = DILUTED OUT

0016305

04:54:30am

SAMPLE ID B7-8P

SAMPLE # 19 FRACTIONS: A

Date & Time Collected 01/18/90 13:45:00 Category SOLID

PCT 8 48
% wt.

0016306

04:54:31 AM

SAMPLE ID B7-8P

FRACTION 19A TEST CODE M8100 NAME Polyaromatic Hydrocarbons
Date & Time Collected 01/18/90 13:45:00 Category SOLID

ANALYST: DDE EXTRACTED: 01/26/90 FILE #: 0129A13A
INSTRMT: HP_II INJECTED: 01/30/90 FACTOR: 33 UNITS: ug/kg

CAS#	COMPOUND	RESULT	DET LIMIT
91-20-3	Naphthalene	BDL	30
208-96-8	Acenaphthylene	BDL	30
83-32-9	Acenaphthene	BDL	30
86-73-7	Fluorene	BDL	30
85-01-8	Phenanthrene	BDL	30
120-12-7	Anthracene	BDL	30
206-44-0	Fluoranthene	BDL	30
129-00-0	Pyrene	BDL	30
56-55-3	Benzo(a)anthracene	BDL	200
218-01-9	Chrysene	BDL	200
205-99-2	Benzo(b)fluoranthene	BDL	200
207-08-9	Benzo(k)fluoranthene	BDL	200
50-32-8	Benzo(a)pyrene	BDL	200
193-39-5	Indeno(1,2,3-cd)pyrene	BDL	200
53-70-3	Dibenzo(a,h)anthracene	BDL	200
191-24-2	Benzo(g,h,i)perylene	BDL	200

VERIFIED: CLM

NOTES AND DEFINITIONS FOR THIS REPORT

DET LIMIT = DETECTION LIMIT
BDL = BELOW DETECTION LIMIT
NA = NOT ANALYZED
NF = NOT FOUND
DL = DILUTED OUT

0016307

04:54:33am

SAMPLE ID B6-2 SAMPLE # 20 FRACTIONS: A
Date & Time Collected 01/18/90 13:05:00 Category SOLID
PCT_S 84 TPH_S 26
% wt. mg/kg

SAMPLE ID B6-8/10 SAMPLE # 21 FRACTIONS: A
Date & Time Collected 01/18/90 13:20:00 Category SOLID
PCT_S 44 TPH_S 70
% wt. mg/kg

SAMPLE ID B7-8 SAMPLE # 22 FRACTIONS: A
Date & Time Collected 01/18/90 13:50:00 Category SOLID
PCT_S 45 TPH_S <25
% wt. mg/kg

SAMPLE ID B6-6 SAMPLE # 23 FRACTIONS: A
Date & Time Collected 01/18/90 13:15:00 Category SOLID
PCT_S 63 TPH_S <25
% wt. mg/kg

0016308

Vapora, Inc.

COMMENT PAGE

* (PCT_S) - Field Blank

0016309

04:54:36am

TEST CODE M8100 NAME Polyaromatic Hydrocarbons

PA Method 8100 SW-846

TEST CODE PCT S NAME Percent Solids

gravimetric, Dried at 103-105 Degrees C

TEST CODE TPH S NAME Petroleum Hydrocarbons

PA Method 418.1

0016310

04:54:37 PM



CHAIN-OF-CUSTODY RECORD

NOTE: Laboratory will homogenize comp. samples

Project Contact: CHARLIE BECK - KURT HAUSNER

Turn Around Requirements: STD

Project No.: 819-100 Project Name: NAVY DFSP

Sampler (print): KURT HAUSNER Signature: [Signature] RUSSELL FRAZEE

Table with columns: Sample I.D. No., Comp, Grab, Date, Time, Sample Location, NUMBER OF SAMPLES, HOLD, % SOLIDS, VOA, ACID EXTRACT, BASE/NEUTR. EXT., EP TOX.-METALS, EP TOX.-METALS, TOT. METALS-ORGAN., TOT. METALS-P.P.L., PCBs, PESTICIDES, FTCS, BETX, ADDITIONAL REQUIREMENTS. Rows include samples B7-10, B7-4, B7-2, B7-6, B6-4, B6-5P, B7-8P, B6-2, B6-8/10, B7-8, B6-6.

Relinquished by: [Signature] Date: 1/19/00 Time: 1600 Received by: [Signature] Date: 1/19/00 Time: 1340 Remarks: 30-Dec-1993 04:54:59 am



CHAIN-OF-CUSTODY RECORD

NOTE: Laboratory will homogenize comp. samples

Project Contact: Charlie Beck or Kurt Hausper

Turn Around Requirements: STD

Project No.: 819-400 Project Name: NAVY DFSP

Sampler (print): Kurt Hausper Signature: [Signature] Russ FRAZE

Sample I.D. No.	Comp	Grab	Date	Time	Sample Location	NUMBER OF SAMPLES	HOLD	% SOLIDS	VOA	ACID EXTRACT.	BASE/NEUTR.	EP TOX.-EXT.	EP TOX.-METALS	TOT. METALS-ORGAN.	TOT. METALS-P.P.L.	PCBs	PESTICIDES	PHOSPH	BETX	M/H	ADDITIONAL REQUIREMENTS	
B11-8/10		X	8/10	1545	B11-8/10	1																
B8-8/10		X		1420	B8-8/10	1																
B11-4		X		1530	B11-4	1																
B8-6		X		1415	B8-6	1																
B8-2		X		1405	B8-2	1																
B8-4		X		1410	B8-4	1																
TRIP BLANK 1		X		1300	TRIP BLANK 1	1																
B9-2		X		1505	B9-2	1																
TRIP BLANK 2		X		1300	TRIP BLANK 2	1																
TRIP BLANK		X		1300	TRIP BLANK	1																
B9-4		X		1510	B9-4	1																
B11-2P		X		1525	B11-2P	1																

Relinquished by: (Signature) [Signature]	Date: 8/18	Time: 1600	Received by: (Signature)	Relinquished by: (Signature)	Date	Time	Received by: (Signature)
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Relinquished by: (Signature)	Date	Time	Received for Laboratory by: (Signature) [Signature]	Date: 8/19	Time: 1540	Remarks:	30-Dec-1993 04:55:00am
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Page 1
Received: 01/19/90

KEMRON

02/02/90 15:00:49

REPORT

Work Order # N0-01-214

REPORT Wapora, Inc.
TO 1815 Century Blvd.
Suite 150
Atlanta, GA 30345
ATTEN John Dwyer
CLIENT WAPATL 59227 SAMPLES 27
COMPANY Wapora, Inc.
LOCALITY Atlanta

PREPARED KEMRON ENVIRONMENTAL SERVICES
BY 109 STARLITE PARK
MARIETTA, OHIO 45750

ATTEN _____
PHONE (614) 373-4071

Leslie J. Galt
CERTIFIED BY

CONTACT H BUSKIRK

ALL WORK PERFORMED IN ACCORDANCE WITH STANDARD METHODOLOGY.

WORK ID 819-400/Navy-DFSP
TAKEN Client
TRANS Fed Ex
TYPE _____
P.O. # _____
INVOICE under separate cover

SAMPLE IDENTIFICATION

B2-6
B2-4
B2-2
B10-4
B1-4
B1-10
B1-8
B10-8
B5-8
B5-10
B1-6
B1-2
B3-2
B3-4
B3-6
B5-6
B3-10
B3-8
B4-2
B4-4
B4-8

TEST CODES and NAMES used on this report

M8100 Polyaromatic Hydrocarbons
PCT S Percent Solids
TPH S Petroleum Hydrocarbons

0016313

04:55:02 AM **KEMRON**
ENVIRONMENTAL SERVICES

Page 2
Received: 01/19/90

KEMRON

REPORT

Work Order # N0-01-214

02/02/90 15:00:49

SAMPLE IDENTIFICATION

2	<u>B5-4</u>
3	<u>B5-2</u>
4	<u>B4-6</u>
5	<u>B9-2P</u>
6	<u>B9-8/10</u>
7	<u>B9-6</u>

0016314

04:55:03 AM
KEMRON
ENVIRONMENTAL SERVICES

SAMPLE ID B2-6 SAMPLE # 01 FRACTIONS: A
Date & Time Collected 01/17/90 10:45:00 Category SOLID

PCT_S 77 TPH_S <25
% wt. mg/kg

SAMPLE ID B2-4 SAMPLE # 02 FRACTIONS: A
Date & Time Collected 01/17/90 10:40:00 Category SOLID

PCT_S 78 TPH_S <25
% wt. mg/kg

SAMPLE ID B2-2 SAMPLE # 03 FRACTIONS: A
Date & Time Collected 01/17/90 10:35:00 Category SOLID

PCT_S 82 TPH_S <25
% wt. mg/kg

SAMPLE ID B10-4 SAMPLE # 04 FRACTIONS: A
Date & Time Collected 01/17/90 15:00:00 Category SOLID

PCT_S 78 TPH_S <25
% wt. mg/kg

SAMPLE ID B1-4 SAMPLE # 05 FRACTIONS: A
Date & Time Collected 01/17/90 10:10:00 Category SOLID

PCT_S 82 TPH_S <25
% wt. mg/kg

SAMPLE ID B1-10 SAMPLE # 06 FRACTIONS: A
Date & Time Collected 01/17/90 10:25:00 Category SOLID

PCT_S 75 TPH_S <25
% wt. mg/kg

04:55:10am

SAMPLE ID <u>B1-8</u>	SAMPLE # <u>07</u> FRACTIONS: <u>A</u>
	Date & Time Collected <u>01/17/90 10:20:00</u> Category <u>SOLID</u>
PCT <u>S</u> <u>79</u> TPH <u>S</u> <u><25</u>	
% wt.	mg/kg
SAMPLE ID <u>B10-8</u>	SAMPLE # <u>08</u> FRACTIONS: <u>A</u>
	Date & Time Collected <u>01/17/90 15:15:00</u> Category <u>SOLID</u>
PCT <u>S</u> <u>77</u> TPH <u>S</u> <u><25</u>	
% wt.	mg/kg
SAMPLE ID <u>B5-8</u>	SAMPLE # <u>09</u> FRACTIONS: <u>A</u>
	Date & Time Collected <u>01/17/90 12:50:00</u> Category <u>SOLID</u>
PCT <u>S</u> <u>76</u> TPH <u>S</u> <u><25</u>	
% wt.	mg/kg
SAMPLE ID <u>B5-10</u>	SAMPLE # <u>10</u> FRACTIONS: <u>A</u>
	Date & Time Collected <u>01/17/90 12:55:00</u> Category <u>SOLID</u>
PCT <u>S</u> <u>77</u> TPH <u>S</u> <u><25</u>	
% wt.	mg/kg
SAMPLE ID <u>B1-6</u>	SAMPLE # <u>11</u> FRACTIONS: <u>A</u>
	Date & Time Collected <u>01/17/90 10:15:00</u> Category <u>SOLID</u>
PCT <u>S</u> <u>78</u> TPH <u>S</u> <u><25</u>	
% wt.	mg/kg
SAMPLE ID <u>B1-2</u>	SAMPLE # <u>12</u> FRACTIONS: <u>A</u>
	Date & Time Collected <u>01/17/90 10:05:00</u> Category <u>SOLID</u>
PCT <u>S</u> <u>82</u> TPH <u>S</u> <u><25</u>	
% wt.	mg/kg

KEMRON REPORT
Results by Sample

Work Order # NO-0114

SAMPLE ID B3-2 SAMPLE # 13 FRACTIONS: A
Date & Time Collected 01/17/90 11:05:00 Category SOLID

PCT_S 88 TPH_S <25
% wt. mg/kg

SAMPLE ID B3-4 SAMPLE # 14 FRACTIONS: A
Date & Time Collected 01/17/90 11:10:00 Category SOLID

PCT_S 80 TPH_S <25
% wt. mg/kg

SAMPLE ID B3-6 SAMPLE # 15 FRACTIONS: A
Date & Time Collected 01/17/90 11:15:00 Category SOLID

PCT_S 72 TPH_S <25
% wt. mg/kg

SAMPLE ID B5-6 SAMPLE # 16 FRACTIONS: A
Date & Time Collected 01/17/90 12:45:00 Category SOLID

PCT_S 84 TPH_S <25
% wt. mg/kg

SAMPLE ID B3-10 SAMPLE # 17 FRACTIONS: A
Date & Time Collected 01/17/90 11:25:00 Category SOLID

PCT_S 77 TPH_S <25
% wt. mg/kg

SAMPLE ID B3-8 SAMPLE # 18 FRACTIONS: A
Date & Time Collected 01/17/90 11:20:00 Category SOLID

PCT_S 81 TPH_S <25
% wt. mg/kg

04:55:13am

KEMRON
ENVIRONMENTAL SERVICES

0016317

SAMPLE ID B4-2 SAMPLE # 19 FRACTIONS: A
Date & Time Collected 01/17/90 12:05:00 Category SOLID

PCT_S 76 TPH_S <25
% wt. mg/kg

SAMPLE ID B4-4 SAMPLE # 20 FRACTIONS: A
Date & Time Collected 01/17/90 12:10:00 Category SOLID

PCT_S 90 TPH_S <25
% wt. mg/kg

SAMPLE ID B4-8 SAMPLE # 21 FRACTIONS: A
Date & Time Collected 01/17/90 12:20:00 Category SOLID

PCT_S 82 TPH_S <25
% wt. mg/kg

SAMPLE ID B5-4 SAMPLE # 22 FRACTIONS: A
Date & Time Collected 01/17/90 12:40:00 Category SOLID

PCT_S 51 TPH_S <25
% wt. mg/kg

SAMPLE ID B5-2 SAMPLE # 23 FRACTIONS: A
Date & Time Collected 01/17/90 12:35:00 Category SOLID

PCT_S 70 TPH_S <25
% wt. mg/kg

SAMPLE ID B4-6 SAMPLE # 24 FRACTIONS: A
Date & Time Collected 01/17/90 12:15:00 Category SOLID

PCT_S 82 TPH_S <25
% wt. mg/kg

01-17-90 12:14:22

Page .
received: 19/90

KEMRON REPORT
Results by Sample

Work Order # NO-014

SAMPLE ID B9-2P SAMPLE # 25 FRACTIONS: A
Date & Time Collected 01/18/90 15:25:00 Category SOLID

PCT_S 65
% wt.

0016319

SAMPLE ID B9-2P FRACTION 25A TEST CODE M8100 NAME Polyaromatic Hydrocarbons
Date & Time Collected 01/18/90 15:25:00 Category SOLID

ANALYST: DDE EXTRACTED: 01/26/90 FILE #: 0129A14A
INSTRMT: HP_II INJECTED: 01/30/90 FACTOR: 33 UNITS: ug/kg

CAS#	COMPOUND	RESULT	DET	LIMIT	VERIFIED: CLM
91-20-3	Naphthalene	BDL		30	
208-96-8	Acenaphthylene		155	30	
83-32-9	Acenaphthene	BDL		30	
86-73-7	Fluorene	BDL		30	
85-01-8	Phenanthrene	BDL		30	
120-12-7	Anthracene	BDL		30	
206-44-0	Fluoranthene		97	30	
129-00-0	Pyrene	BDL		30	
56-55-3	Benzo(a)anthracene	BDL		200	
218-01-9	Chrysene	BDL		200	
205-99-2	Benzo(b)fluoranthene	BDL		200	
207-08-9	Benzo(k)fluoranthene	BDL		200	
50-32-8	Benzo(a)pyrene	BDL		200	
193-39-5	Indeno(1,2,3-cd)pyrene	BDL		200	
53-70-3	Dibenzo(a,h)anthracene	BDL		200	
191-24-2	Benzo(g,h,i)perylene	BDL		200	

NOTES AND DEFINITIONS FOR THIS REPORT
DET LIMIT = DETECTION LIMIT
BDL = BELOW DETECTION LIMIT
NA = NOT ANALYZED
NF = NOT FOUND
DL = DILUTED OUT

0016320

04:55:18 PM

KEMRON
ENVIRONMENTAL SERVICES

SAMPLE ID B9-8/10

SAMPLE # 26 FRACTIONS: A

Date & Time Collected 01/18/90 15:20:00 Category SOLID

PCT_S 55 TPH_S <25
% wt. mg/kg

SAMPLE ID B9-6

SAMPLE # 27 FRACTIONS: A

Date & Time Collected 01/18/90 15:15:00 Category SOLID

PCT_S 44 TPH_S <25
% wt. mg/kg

0016321

04:55:19 AM

Page 10
Received: 01/19/90

KEMRON

REPORT
Test Methodology

Work Order # NO-01-214

EST CODE M8100 NAME Polyaromatic Hydrocarbons

PA Method 8100 SW-846

EST CODE PCT S NAME Percent Solids

gravimetric, Dried at 103-105 Degrees C

EST CODE TPH S NAME Petroleum Hydrocarbons

PA Method 418.1

0016322

04:55:20am

Kemron
ENVIRONMENTAL SERVICES



CHAIN-OF-CUSTODY RECORD

NOTE: Laboratory will homogenize comp. samples

Project Contact: CHARLIE BECK or KURT HAUSNER

Turn Around Requirements: STD.

Project No.: 819-400 Project Name: NAVY - DFSP

Sampler (print): KURT HAUSNER Signature: Kurt Hausner

Russ Frazz

Table with columns: Sample I.D. No., Comp, Grab, Date, Time, Sample Location, NUMBER OF SAMPLES, HOLD, % SOLIDS, VOA, ACID EXTRACT, BASE/NEUTR. EXT., EP TOX.-METALS, EP TOX.-ORGAN., TOT. METALS-P.P.L., PCBS, PESTICIDES, PHOS TPH, BETX, ADDITIONAL REQUIREMENTS. Rows include samples B2-6, B2-4, B2-2, B10-4, B1-4, B1-10, B1-8, B10-8, B5-8, B5-10, B1-6, B1-2.

Relinquished by: (Signature) Kurt Hausner Date: 1/18/05 Time: 1600 Received by: (Signature) Date: Time: Received by: (Signature)

Relinquished by: (Signature) Date: Time: Received for Laboratory by: (Signature) Date: 1/19/05 Time: 1505 Remarks: 30-Dec-1993 04:55:22am

REPORT Wapora, Inc.
TO 1815 Century Blvd.
Suite 150
Atlanta, GA 30345
ATTEN Russ Fraze

PREPARED KEMRON ENVIRONMENTAL SERVICES
BY 109 STARLITE PARK
MARIETTA, OHIO 45750

Leslie J. Lytle
CERTIFIED BY

ATTEN _____
PHONE (614) 373-4071

CONTACT H BUSKIRK

CLIENT WAPATL 59227 SAMPLES 9
COMPANY Wapora, Inc.
FACILITY Atlanta
FAX # (404) 636-7162

ANALYTICAL METHODS AND DOCUMENTATION ARE FOUND AT THE END OF
THIS REPORT. ALL RESULTS ON SOILS/SLUDGES ARE REPORTED
"AS RECEIVED" UNLESS OTHERWISE SPECIFIED.

WORK ID 819-500/Navy DFSP
TAKEN R.F. & R.S.
TRANS Fed Ex
TYPE _____
P.O. # _____
INVOICE under separate cover

SAMPLE IDENTIFICATION

TEST CODES and NAMES used on this report

- 01 MW-1
- 02 MW-2
- 03 MW-3
- 04 MW-4
- 05 MW-5
- 06 MW-6
- 07 MW-7
- 08 MW-8
- 09 Trip Blank

- BETX Volatile Organics (BETX)
- M8100 Polyaromatic Hydrocarbons
- TPH Petroleum Hydrocarbons

0016325

SAMPLE ID <u>MW-1</u>	SAMPLE # <u>01</u> FRACTIONS: <u>A,B</u>
	Date & Time Collected <u>02/26/90 09:30:00</u> Category <u>WATER</u>
TPH <u>1.4</u>	
mg/l	

0016326

04:55:26 AM

SAMPLE ID MW-1 FRACTION 01B TEST CODE M8100 NAME Polyaromatic Hydrocarbons
Date & Time Collected 02/26/90 09:30:00 Category WATER

ANALYST: SWC EXTRACTED: 02/28/90 FILE #: 0301A10A
INSTRMT: HP_II INJECTED: 03/02/90 FACTOR: 1 UNITS: ug/L

CAS#	COMPOUND	RESULT	DET LIMIT	VERIFIED: RJW
91-20-3	Naphthalene	BDL	1	
208-96-8	Acenaphthylene	BDL	1	
83-32-9	Acenaphthene	BDL	1	
86-73-7	Fluorene	BDL	1	
85-01-8	Phenanthrene	BDL	1	
120-12-7	Anthracene	BDL	1	
206-44-0	Fluoranthene	BDL	1	
129-00-0	Pyrene	BDL	1	
56-55-3	Benzo(a)anthracene	BDL	5	
218-01-9	Chrysene	BDL	5	
205-99-2	Benzo(b)fluoranthene	BDL	5	
207-08-9	Benzo(k)fluoranthene	BDL	5	
50-32-8	Benzo(a)pyrene	BDL	5	
193-39-5	Indeno(1,2,3-cd)pyrene	BDL	5	
53-70-3	Dibenzo(a,h)anthracene	BDL	5	
191-24-2	Benzo(g,h,i)perylene	BDL	5	

NOTES AND DEFINITIONS FOR THIS REPORT
DET LIMIT = DETECTION LIMIT
BDL = BELOW DETECTION LIMIT
NA = NOT ANALYZED
NF = NOT FOUND
DL = DILUTED OUT

0016327

SAMPLE ID <u>MW-2</u>	SAMPLE # <u>02</u> FRACTIONS: <u>A,B</u>
	Date & Time Collected <u>02/26/90 10:00:00</u> Category <u>WATER</u>
TPH <u><1</u> mg/l	

0016328

SAMPLE ID MW-2 FRACTION 02B TEST CODE M8100 NAME Polyaromatic Hydrocarbons
Date & Time Collected 02/26/90 10:00:00 Category WATER

ANALYST: SWC EXTRACTED: 02/28/90 FILE #: 0301A11A
INSTRMT: HP_II INJECTED: 03/02/90 FACTOR: 1 UNITS: ug/L

CAS#	COMPOUND	RESULT	DET LIMIT	VERIFIED: RJW
91-20-3	Naphthalene	BDL	1	
208-96-8	Acenaphthylene	BDL	1	
83-32-9	Acenaphthene	BDL	1	
86-73-7	Fluorene	2	1	
85-01-8	Phenanthrene	BDL	1	
120-12-7	Anthracene	BDL	1	
206-44-0	Fluoranthene	BDL	1	
129-00-0	Pyrene	3	1	
56-55-3	Benzo(a)anthracene	BDL	5	
218-01-9	Chrysene	BDL	5	
205-99-2	Benzo(b)fluoranthene	BDL	5	
207-08-9	Benzo(k)fluoranthene	BDL	5	
50-32-8	Benzo(a)pyrene	BDL	5	
193-39-5	Indeno(1,2,3-cd)pyrene	BDL	5	
53-70-3	Dibenzo(a,h)anthracene	BDL	5	
191-24-2	Benzo(g,h,i)perylene	BDL	5	

NOTES AND DEFINITIONS FOR THIS REPORT

DET LIMIT = DETECTION LIMIT
BDL = BELOW DETECTION LIMIT
NA = NOT ANALYZED
NF = NOT FOUND
DL = DILUTED OUT

0016329

04:55:31am

KEMRON
ENVIRONMENTAL SERVICES

SAMPLE ID MW-3

SAMPLE # 03 FRACTIONS: A,B,C

Date & Time Collected 02/26/90 10:00:00 Category WATER

TPH <1
mg/l

0016330

04:55:32PM

KEMRON
ENVIRONMENTAL SERVICES

SAMPLE ID MW-3 FRACTION 03C TEST CODE BETX NAME Volatile Organics (BETX)
Date & Time Collected 02/26/90 10:00:00 Category WATER

ANALYST: WSN FILE #: 3WA3669
INSTRMT: FINN_3 INJECTED: 02/28/90 FACTOR: 1 UNITS: ug/L VERIFIED

CAS#	COMPOUND	RESULT	DET LIMIT
71-43-2	Benzene	BDL	5
100-41-4	Ethyl benzene	BDL	5
108-88-3	Toluene	BDL	5
1330-20-7	Xylenes, Total	BDL	5

SURROGATES		
1,2-Dichloroethane-d4	<u>96</u>	% Recovery
Toluene-d8	<u>101</u>	% Recovery
4-Bromofluorobenzene	<u>89</u>	% Recovery

NOTES AND DEFINITIONS FOR THIS REPORT.
DET LIMIT = DETECTION LIMIT
BDL=BELOW DETECTION LIMIT
NA = NOT ANALYZED
BQL = BELOW QUANTITATION LIMIT

0016331

04:55:34am

SAMPLE ID MW-3 FRACTION 03B TEST CODE M8100 NAME Polyaromatic Hydrocarbons
Date & Time Collected 02/26/90 10:00:00 Category WATER

ANALYST: SWC EXTRACTED: 02/28/90 FILE #: 0301A12A
INSTRMT: HP_II INJECTED: 03/02/90 FACTOR: 1 UNITS: ug/L

CAS#	COMPOUND	RESULT	DET LIMIT
91-20-3	Naphthalene	BDL	1
208-96-8	Acenaphthylene	BDL	1
83-32-9	Acenaphthene	9	1
86-73-7	Fluorene	5	1
85-01-8	Phenanthrene	8	1
120-12-7	Anthracene	2	1
206-44-0	Fluoranthene	14	1
129-00-0	Pyrene	15	1
56-55-3	Benzo(a)anthracene	2 *	5
218-01-9	Chrysene	2 *	5
205-99-2	Benzo(b)fluoranthene	BDL	5
207-08-9	Benzo(k)fluoranthene	BDL	5
50-32-8	Benzo(a)pyrene	BDL	5
193-39-5	Indeno(1,2,3-cd)pyrene	BDL	5
53-70-3	Dibenzo(a,h)anthracene	BDL	5
191-24-2	Benzo(g,h,i)perylene	BDL	5

VERIFIED: RJW

NOTES AND DEFINITIONS FOR THIS REPORT

DET LIMIT = DETECTION LIMIT
BDL = BELOW DETECTION LIMIT
NA = NOT ANALYZED
NF = NOT FOUND
DL = DILUTED OUT
* = BELOW NOMINAL METHOD DETECTION LIMIT

04:55:35AM

KEMRON
ENVIRONMENTAL SERVICES

0016332

SAMPLE ID <u>MW-4</u>	SAMPLE # <u>04</u> FRACTIONS: <u>A,B</u>
	Date & Time Collected <u>02/26/90 11:00:00</u> Category <u>WATER</u>
TPH <u><1</u> mg/l	

0016333

04:55:37am



SAMPLE ID MW-4 FRACTION 04B TEST CODE M8100 NAME Polyaromatic Hydrocarbons
Date & Time Collected 02/26/90 11:00:00 Category WATER

ANALYST: SWC EXTRACTED: 02/28/90 FILE #: 0301A13A
INSTRMT: HP_II INJECTED: 03/02/90 FACTOR: 1 UNITS: ug/L

CAS#	COMPOUND	RESULT	DET LIMIT	
91-20-3	Naphthalene	BDL	1	VERIFIED: RJW
208-96-8	Acenaphthylene	BDL	1	
83-32-9	Acenaphthene	BDL	1	
86-73-7	Fluorene	BDL	1	
85-01-8	Phenanthrene	BDL	1	
120-12-7	Anthracene	BDL	1	
206-44-0	Fluoranthene	BDL	1	
129-00-0	Pyrene	BDL	1	
56-55-3	Benzo(a)anthracene	BDL	5	
218-01-9	Chrysene	BDL	5	
205-99-2	Benzo(b)fluoranthene	BDL	5	
207-08-9	Benzo(k)fluoranthene	BDL	5	
50-32-8	Benzo(a)pyrene	BDL	5	
193-39-5	Indeno(1,2,3-cd)pyrene	BDL	5	
53-70-3	Dibenzo(a,h)anthracene	BDL	5	
191-24-2	Benzo(g,h,i)perylene	BDL	5	

NOTES AND DEFINITIONS FOR THIS REPORT

DET LIMIT = DETECTION LIMIT
BDL = BELOW DETECTION LIMIT
NA = NOT ANALYZED
NF = NOT FOUND
DL = DILUTED OUT

0016334

04:55:38 AM

KEMRON
ENVIRONMENTAL SERVICES

SAMPLE ID <u>MW-5</u>	SAMPLE # <u>05</u> FRACTIONS: <u>A,B</u>
	Date & Time Collected <u>02/26/90 12:30:00</u> Category <u>WATER</u>
TPH <u><1</u> mg/l	

0016335

04:55:40am

SAMPLE ID MW-5 FRACTION 05B TEST CODE M8100 NAME Polyaromatic Hydrocarbons
Date & Time Collected 02/26/90 12:30:00 Category WATER

ANALYST: SWC EXTRACTED: 02/28/90 FILE #: 0301A14A
INSTRMT: HP_II INJECTED: 03/02/90 FACTOR: 1 UNITS: ug/L

CAS#	COMPOUND	RESULT	DET LIMIT	VERIFIED: RJW
91-20-3	Naphthalene	BDL	1	
208-96-8	Acenaphthylene	BDL	1	
83-32-9	Acenaphthene	BDL	1	
86-73-7	Fluorene	BDL	1	
85-01-8	Phenanthrene	BDL	1	
120-12-7	Anthracene	BDL	1	
206-44-0	Fluoranthene	BDL	1	
129-00-0	Pyrene	BDL	1	
56-55-3	Benzo(a)anthracene	BDL	5	
218-01-9	Chrysene	BDL	5	
205-99-2	Benzo(b)fluoranthene	BDL	5	
207-08-9	Benzo(k)fluoranthene	BDL	5	
50-32-8	Benzo(a)pyrene	BDL	5	
193-39-5	Indeno(1,2,3-cd)pyrene	BDL	5	
53-70-3	Dibenzo(a,h)anthracene	BDL	5	
191-24-2	Benzo(g,h,i)perylene	BDL	5	

NOTES AND DEFINITIONS FOR THIS REPORT

DET LIMIT = DETECTION LIMIT
BDL = BELOW DETECTION LIMIT
NA = NOT ANALYZED
NF = NOT FOUND
DL = DILUTED OUT

0016336

04:55:41am

SAMPLE ID MW-6

SAMPLE # 06 FRACTIONS: A,B

Date & Time Collected 02/26/90 13:00:00 Category WATER

TPH <1
mg/l

0016337

04:55:43 AM

SAMPLE ID MW-6 FRACTION 06B TEST CODE M8100 NAME Polyaromatic Hydrocarbons
Date & Time Collected 02/26/90 13:00:00 Category WATER

ANALYST: SWC EXTRACTED: 02/28/90 FILE #: 0301A15A
INSTRMT: HP_II INJECTED: 03/02/90 FACTOR: 1 UNITS: ug/L

CAS#	COMPOUND	RESULT	DET LIMIT	VERIFIED: RJW
91-20-3	Naphthalene	BDL	1	
208-96-8	Acenaphthylene	BDL	1	
83-32-9	Acenaphthene	BDL	1	
86-73-7	Fluorene	BDL	1	
85-01-8	Phenanthrene	BDL	1	
120-12-7	Anthracene	BDL	1	
206-44-0	Fluoranthene	BDL	1	
129-00-0	Pyrene	BDL	1	
56-55-3	Benzo(a)anthracene	BDL	5	
218-01-9	Chrysene	BDL	5	
205-99-2	Benzo(b)fluoranthene	BDL	5	
207-08-9	Benzo(k)fluoranthene	BDL	5	
50-32-8	Benzo(a)pyrene	BDL	5	
193-39-5	Indeno(1,2,3-cd)pyrene	BDL	5	
53-70-3	Dibenzo(a,h)anthracene	BDL	5	
191-24-2	Benzo(g,h,i)perylene	BDL	5	

NOTES AND DEFINITIONS FOR THIS REPORT

DET LIMIT = DETECTION LIMIT
BDL = BELOW DETECTION LIMIT
NA = NOT ANALYZED
NF = NOT FOUND
DL = DILUTED OUT

0016338

04:55:44am

KEMRON
ENVIRONMENTAL SERVICES

SAMPLE ID <u>MW-7</u>	SAMPLE # <u>07</u> FRACTIONS: <u>A,B</u>
	Date & Time Collected <u>02/26/90 13:30:00</u> Category <u>WATER</u>
TPH <u><1</u> mg/l	

0016339

04:55:46 AM

SAMPLE ID MW-7 FRACTION 07B TEST CODE M8100 NAME Polyaromatic Hydrocarbons
Date & Time Collected 02/26/90 13:30:00 Category WATER

ANALYST: SWC EXTRACTED: 02/28/90 FILE #: 0301A16A
INSTRMT: HP_II INJECTED: 03/02/90 FACTOR: 1 UNITS: ug/L

CAS#	COMPOUND	RESULT	DET LIMIT	VERIFIED: RJW
91-20-3	Naphthalene	BDL	1	
208-96-8	Acenaphthylene	BDL	1	
83-32-9	Acenaphthene	BDL	1	
86-73-7	Fluorene	BDL	1	
85-01-8	Phenanthrene	BDL	1	
120-12-7	Anthracene	BDL	1	
206-44-0	Fluoranthene	BDL	1	
129-00-0	Pyrene	BDL	1	
56-55-3	Benzo(a)anthracene	BDL	5	
218-01-9	Chrysene	BDL	5	
205-99-2	Benzo(b)fluoranthene	BDL	5	
207-08-9	Benzo(k)fluoranthene	BDL	5	
50-32-8	Benzo(a)pyrene	BDL	5	
193-39-5	Indeno(1,2,3-cd)pyrene	BDL	5	
53-70-3	Dibenzo(a,h)anthracene	BDL	5	
191-24-2	Benzo(g,h,i)perylene	BDL	5	

NOTES AND DEFINITIONS FOR THIS REPORT
DET LIMIT = DETECTION LIMIT
BDL = BELOW DETECTION LIMIT
NA = NOT ANALYZED
NF = NOT FOUND
DL = DILUTED OUT

0016340

04:55:47am

SAMPLE ID <u>MW-8</u>	SAMPLE # <u>08</u> FRACTIONS: <u>A,B</u>
	Date & Time Collected <u>02/26/90 10:30:00</u> Category <u>WATER</u>
TPH <u><1</u> mg/l	

0016341

04:55:49 AM

SAMPLE ID MW-8 FRACTION 08B TEST CODE M8100 NAME Polyaromatic Hydrocarbons
Date & Time Collected 02/26/90 10:30:00 Category WATER

ANALYST: SWC EXTRACTED: 02/28/90 FILE #: 0301A17A
INSTRMT: HP_II INJECTED: 03/02/90 FACTOR: 1 UNITS: ug/L

CAS#	COMPOUND	RESULT	DET LIMIT
91-20-3	Naphthalene	BDL	1
208-96-8	Acenaphthylene	BDL	1
83-32-9	Acenaphthene	BDL	1
86-73-7	Fluorene	EDL	1
85-01-8	Phenanthrene	BDL	1
120-12-7	Anthracene	BDL	1
206-44-0	Fluoranthene	BDL	1
129-00-0	Pyrene	BDL	1
56-55-3	Benzo(a)anthracene	BDL	5
218-01-9	Chrysene	BDL	5
205-99-2	Benzo(b)fluoranthene	BDL	5
207-08-9	Benzo(k)fluoranthene	BDL	5
50-32-8	Benzo(a)pyrene	BDL	5
193-39-5	Indeno(1,2,3-cd)pyrene	BDL	5
53-70-3	Dibenzo(a,h)anthracene	BDL	5
191-24-2	Benzo(g,h,i)perylene	BDL	5

VERIFIED: RJW

NOTES AND DEFINITIONS FOR THIS REPORT

DET LIMIT = DETECTION LIMIT
BDL = BELOW DETECTION LIMIT
NA = NOT ANALYZED
NF = NOT FOUND
DL = DILUTED OUT

0016342

04:55:50am

KEMRON
ENVIRONMENTAL SERVICES

SAMPLE ID Trip Blank

SAMPLE # 09 FRACTIONS: A,B

Date & Time Collected 02/26/90 13:00:00 Category WATER

TPH <1
mg/l

6016343

04:55:52 AM

KEMRON
ENVIRONMENTAL SERVICES

SAMPLE ID Trip Blank FRACTION 09B TEST CODE M8100 NAME Polyaromatic Hydrocarbons
Date & Time Collected 02/26/90 13:00:00 Category WATER

ANALYST: SWC EXTRACTED: 02/28/90 FILE #: 0301A18A
INSTRMT: HP_II INJECTED: 03/02/90 FACTOR: 1 UNITS: ug/L

CAS#	COMPOUND	RESULT	DET LIMIT	VERIFIED: RJW
91-20-3	Naphthalene	BDL	1	
208-96-8	Acenaphthylene	BDL	1	
83-32-9	Acenaphthene	BDL	1	
86-73-7	Fluorene	BDL	1	
85-01-8	Phenanthrene	BDL	1	
120-12-7	Anthracene	BDL	1	
206-44-0	Fluoranthene	BDL	1	
129-00-0	Pyrene	BDL	1	
56-55-3	Benzo(a)anthracene	BDL	5	
218-01-9	Chrysene	BDL	5	
205-99-2	Benzo(b)fluoranthene	BDL	5	
207-08-9	Benzo(k)fluoranthene	BDL	5	
50-32-8	Benzo(a)pyrene	BDL	5	
193-39-5	Indeno(1,2,3-cd)pyrene	BDL	5	
53-70-3	Dibenzo(a,h)anthracene	BDL	5	
191-24-2	Benzo(g,h,i)perylene	BDL	5	

NOTES AND DEFINITIONS FOR THIS REPORT

DET LIMIT = DETECTION LIMIT
BDL = BELOW DETECTION LIMIT
NA = NOT ANALYZED
NF = NOT FOUND
DL = DILUTED OUT

0016344

04:55:53am

KEMRON
ENVIRONMENTAL SERVICES

Page 21
Received: 12/27/90

KEMRON

REPORT
Test Methodology

Work Order # N0-02-284

TEST CODE BETX NAME Volatile Organics (BETX)

EPA Method 8240 (SW-846)

TEST CODE M8100 NAME Polyaromatic Hydrocarbons

EPA Method 8100 SW-846

TEST CODE TPH NAME Petroleum Hydrocarbons

EPA Method 418.1

0016345

04:55:55am

KEMRON
ENVIRONMENTAL SERVICES

QUALITY ASSURANCE SECTION
AND
ATTACHMENTS

- . BFB Summary-Method 624, 8240 (VOA)
- . Method 624, 8240 (VOA) Standard RIC
- . Method 624, 8240 (VOA) Blank RIC
- . Method 624, 8240 (VOA) Sample RIC
- . Mass Spectra - Identified VOA Compounds
- . Glossary
- . Chain-of-Custody Record
(if initiated by client)

Tuning Report
 02/28/90 8:20:00 + 6:49
 Instrument: FINN_3
 Base Number:

Data: 3BF3660 # 155
 Call: 3CAL0228 # 3
 Analyst: WSN
 Laboratory: KEMRON # 2

Base m/z: 95
 RIC: 248320.
 Acct. No.:
 Contract:

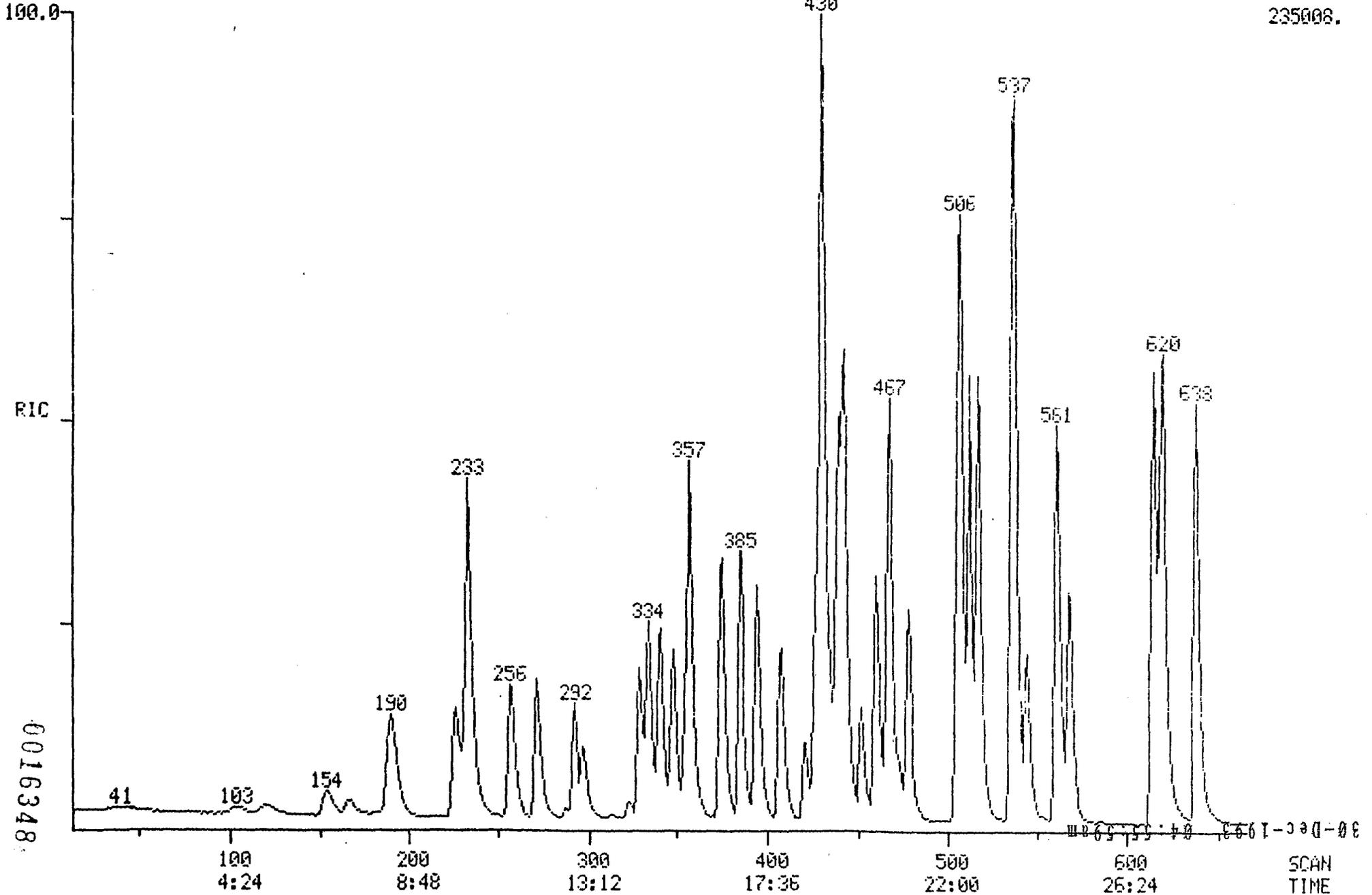
30-Dec-1993 04:55:58am

m/z	Intensity	% RA	Ion Abundance Criteria			Actual	Status
			Min %	Max %	Mass		
50	7832.	17.7	15.0	40.0	95	17.7	PASS
75	19712.	44.6	30.0	60.0	95	44.6	PASS
95	44160.	100.0	100.0	---	---	100.0	PASS
96	2968.	6.7	5.0	9.0	95	6.7	PASS
173	17.	0.0	---	2.0	174	0.0	PASS
174	35904.	81.3	50.0	---	95	81.3	PASS
175	2720.	6.2	5.0	9.0	174	7.6	PASS
176	35264.	79.9	95.0	101.0	174	98.2	PASS
177	2228.	5.0	5.0	9.0	176	6.3	PASS

2011

RIC DATA: 3ST3661 #1 SCANS 15 TO 666
 02/28/90 8:31:00 CALI: 3ST3661 #3
 SAMPLE: USTD050 UOA STD 50PPB +DCB CONTINUING CALIBRATION 5ML
 CONDS.: -10FOR1MIN -10TO16006 160FOR10 PURGE 22ML/MIN
 RANGE: G 1. 666 LABEL: N 0. 4.0 QUAN: A 0. 1.0 J 0 BASE: U 20. 3

235008.

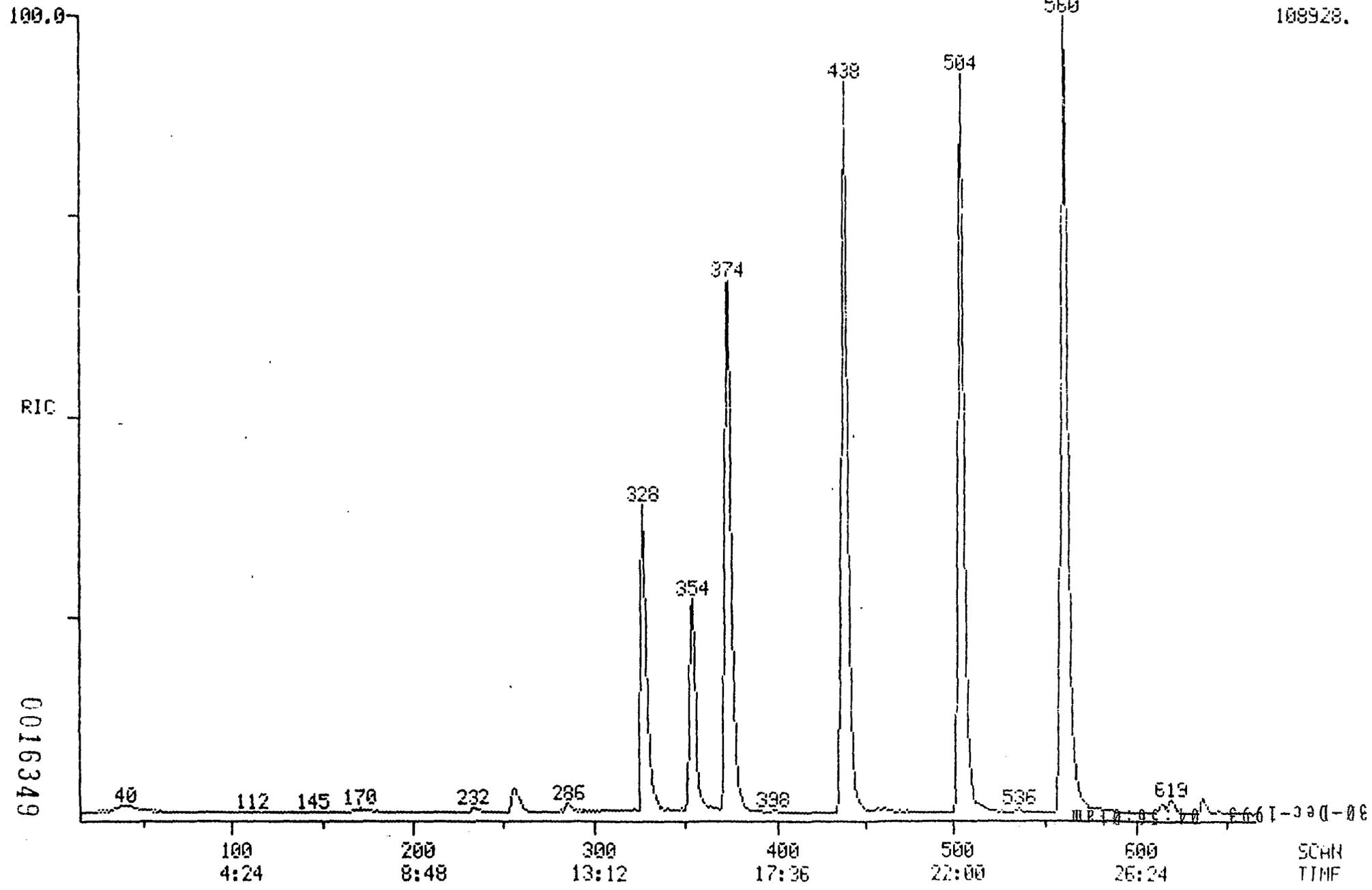


0016348

30-D-100-00

003

RIC DATA: 3BK3552 #1 SCANS 15 TO 555
 02/28/90 9:24:00 CALI: 3BK3552 #3
 SAMPLE: UBLK0228 UOA BLANK 5ML
 CONDS.: -10FOR1MIN -10TO16005 160FOR10 PURGE 22ML/MIN
 RANGE: G 1, 555 LABEL: N 0, 4.0 QUAN: A 0, 1.0 J 0 BASE: U 20, 3



0016349

108928.

001-001-00

SCAN TIME

014

RIC

02/28/90 14:39:00

SAMPLE: WAPORA 02-284-03

5ML

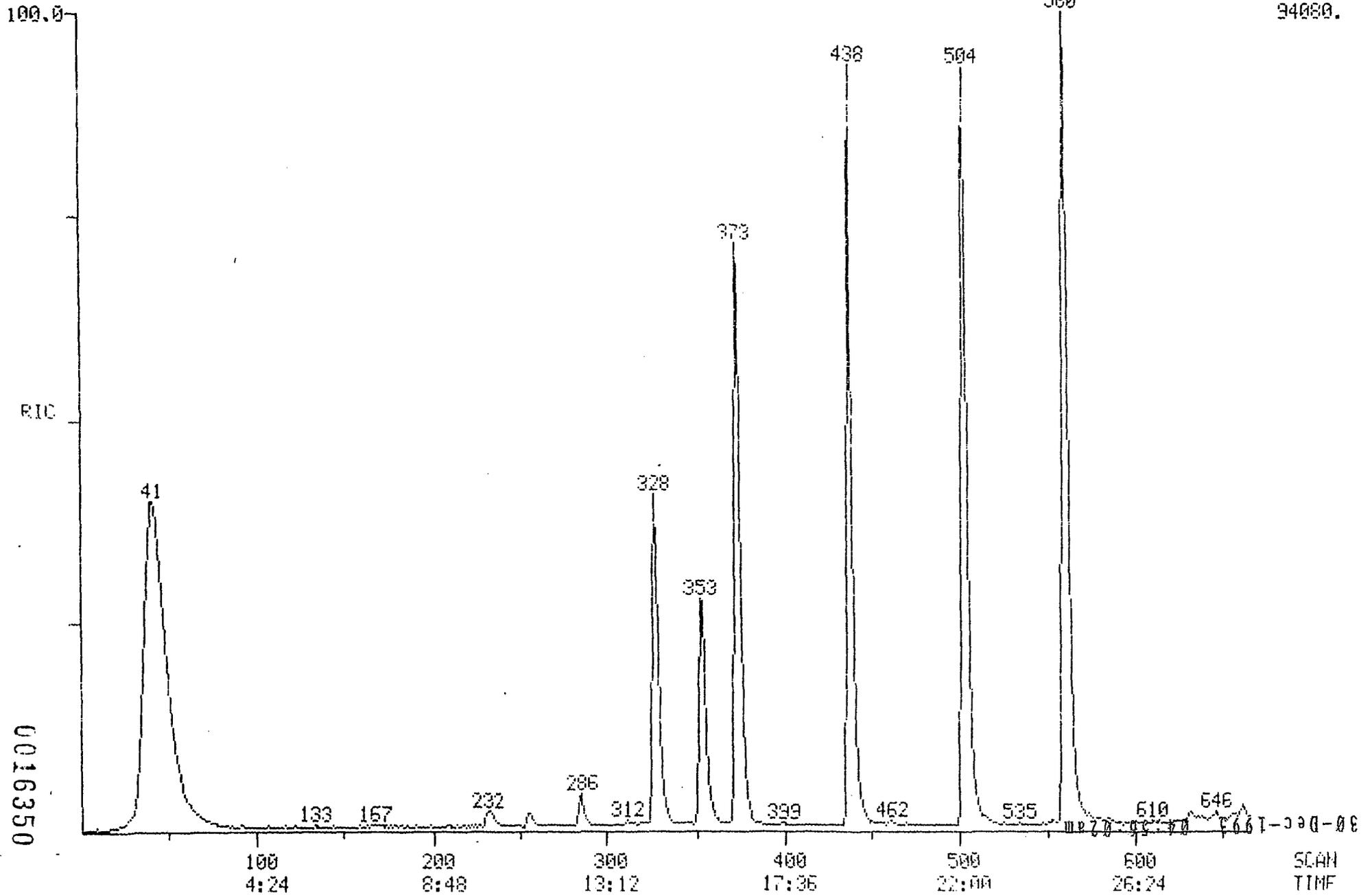
CONDS.: -10FOR1MIN -10TO15000 150FOR10 PURGE 22ML/MIN

RANGE: G 1, 666 LABEL: N 0, 4.0 QUAN: A 0, 1.0 J 0 BASE: U 20, 3

DATA: 3WA3569 #1

SCANS 1 TO 666

CALI: 3WA3569 #3



94080.

0016350

0016350

SCAN TIME

GLOSSARY

38-Dec-1993 04:56:04am

- BFB:** Bromofluorobenzene; the compound specified in EPA Method 624/8240 for which the mass spectrometer must meet performance criteria for VOA analysis.
- DFTPP:** Decafluorotriphenylphosphine; the compound specified in EPA Method 625/8270 for which the mass spectrometer must meet performance criteria for semivolatile compounds.
- EPA Method 624:** GC/MS method for determining volatile organic compounds in water using the purge and trap technique.
- EPA Method 625:** GC/MS method for determining semivolatile organic compounds in water using liquid/liquid extraction.
- EPA Method 8240:** GC/MS Method for determining volatile organic compounds in a variety of water and waste matrices using the purge and trap technique. Reference: SW-846.
- EPA Method 8270:** GC/MS Method for determining semivolatile organic compounds in a variety of water and waste matrices using liquid/liquid extraction and capillary column technique. Reference: SW-846.
- IS:** Internal Standard: compound used to determine response factors (RF) for individual analytes and subsequent quantitative analysis.
- RIC:** Reconstructed Ion Chromatograph; GC/MS chromatograph which plots total ion current versus scan number (time).
- SS:** Surrogate Standard; quality control compounds similar to the compounds of interest which are spiked into every sample matrix. The surrogate's recovery is determined using the same internal standard procedures and the analytes.
- VOA:** Volatile Organic Analysis; see EPA Method 624/8240.
- SV:** Semivolatile compounds; refers to the analytes determined by liquid/liquid extraction technique Method 625/8270.

0016351

FACTORS AFFECTING BIODEGRADATION RATES

A careful analysis of the biodegradation and disappearance rates listed in Table 9.9 reveals that several rates for one chemical have been reported in the published literature. For example, the time to attain 100 percent disappearance for toluene in soil incubation studies ranged from seven days to about 120 weeks. It is most important to recognize that, in addition to chemical structure, a number of soil factors affect the biodegradation and disappearance rates of organic chemicals. The manipulation and optimization of these factors is needed in order to neutralize the effects of Leibig's Law of the Minimum. This law states that the rate of a biological process such as growth or metabolism is limited by the factor present at its minimum level. In other words, if all the soil factors discussed in this section are adjusted to their optimum level, then the biodegradation or disappearance rate of an organic chemical will also be at its optimum. On the other hand, if all factors except one were at their optimum levels, the rate of biodegradation or disappearance would be significantly reduced due to the one factor.

The Composition and Size of the Soil Microbial Population. The biodegradation rate of an organic chemical is generally dependent upon (a) the presence of soil microorganisms capable of degrading the chemical, and (b) the number of these organisms present in the soil system. The relationship between degradation and population size should be obvious: the greater the number of microorganisms capable of degrading the chemical, the faster the degradation of the chemical.

The size of the soil microorganism population is greatest generally in the surface horizons of soil. In this region the soil temperature, moisture, aeration, and energy supply are at relatively more favorable levels for supporting microorganisms.

The size of the soil microorganism population is not constant. It may change as the soil environment changes. For example, large population changes have been observed due to the addition of oil to soil. The naturally-occurring soil microorganism population includes several genera of bacteria and fungi capable of degrading petroleum products. In decreasing order *Pseu-*

TABLE 9.9 Biodegradation and Disappearance Rates for Several Organic Chemicals^a

<i>Organic Chemical</i>	<i>Biodegradation or Disappearance Rate</i>	<i>Medium and Inoculum</i>	<i>Reference</i>
acenaphthene	98% in 7d	scf, sdw	38
	< 60d half life	si, nmf	39
	6.6%/w - 100% in 1w	si, naf	40
acenaphthylene	96% in 7d	scf, sdw	38
	100% in 4 mo	si, nmf	41
acetanilide	14.7 mgCOD/g/h	bss, as	42
acetophenone	4d half life	sgw, fo	43
acrolein	100% in 7d	scf, sdw	38
acrylonitrile	100% in 7d	scf, sdw	38
aldrin	0% in 7d	scf, sdw	38
alkanes (C6 to C10)	< 4d half life	sgw, fo	43
4-aminoacetanilide	11.3 mgCOD/g/h	bss, as	42
2-aminobenzoic acid	27.1 mgCOD/g/h	bss, as	42
3-aminobenzoic acid	7.0 mgCOD/g/h	bss, as	42
4-aminobenzoic acid	12.5 mgCOD/g/h	bss, as	42
2-aminopentanedioic acid	2.5-18.1h aerobic half life	si, nmf	44
	1.7-16.7h anaerobic half life	si, nmf	44
	11-14d half life	gwi, nmf	45
2-aminophenol	21.1 mgCOD/g/h	bss, as	42
3-aminophenol	10.6 mgCOD/g/h	bss, as	42
4-aminophenol	16.7 mgCOD/g/h	bss, as	42
aminophenol-sulphonic acid	7.1 mgCOD/g/h	bss, as	42
2-aminopyridine	55% in 64d	si, nmf	46
3-aminopyridine	64% in 64d	si, nmf	46
4-aminopyridine	6% in 64d	si, nmf	46
2-aminotoluene	15.1 mgCOD/g/h	bss, as	42
3-aminotoluene	30 mgCOD/g/h	bss, as	42
4-aminotoluene	20 mgCOD/g/h	bss, as	42
ammonium oxalate	9.3 mgCOD/g/h	bss, as	42
aniline	19 mgCOD/g/h	bss, as	42
anthracene	35% in 7d	scf, sdw	38
	93% in 16 mo	si, nmf	41
	200-460d half life	si, nmf	39
aroclor 1016	33% in 7d	scf, sdw	38
aroclor 1221	100% in 7d	scf, sdw	38
aroclor 1232	100% in 7d	scf, sdw	38
aroclor 1242	36% in 7d	scf, sdw	38
aroclor 1248	0% in 7d	scf, sdw	38
aroclor 1254	11% in 7d	scf, sdw	38
aroclor 1260	0% in 7d	scf, sdw	38
benzaldehyde	119 mgCOD/g/h	bss, as	42
benz(a)anthracene	8% in 7d	scf, sdw	38
	36% in 16 mo	si, nmf	41

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APPENDIX D
FACTORS AFFECTING BIODEGRADATION RATES

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TABLE 9.9 Biodegradation and Disappearance Rates for Several Organic Chemicals^a (cont.)

<i>Organic Chemical</i>	<i>Biodegradation or Disappearance Rate</i>	<i>Medium and Inoculum</i>	<i>Reference</i>
benz(a)anthracene (contd)	240-680d half life	si, nmf	41
benzene	43% in 7d	scf, sdw	38
	110d half life	sgw, fo	43
	68d half life	sgw, fo	47
	48d half life	gwi, nmf	47
	20-90% in 80d	si, nmf	48
	100% in 434d	sgw, fo	48
	>99% in 120w	si, nmf	49
m-benzene-			
disulphonic acid	3.4 mgCOD/g/h	bss, as	42
benzenesulphonic acid	10.6 mgCOD/g/h	bss, as	42
benzo(b)fluoranthene	360-610d half life	si, nmf	39
benzo(k)fluoranthene	910-1400d half life	si, nmf	39
benzoic acid	88.5 mgCOD/g/h	bss, as	42
	7.3h (ring) aerobic half life	si, nmf	44
	3.9h (carboxyl) aerobic half life	si, nmf	44
	18.2h (ring) anaerobic half life	si, nmf	44
	26d (ring) half life	gwi, nmf	45
	41d (carboxyl) half life	gwi, nmf	45
benzo(g,h,i)perylene	590-650d half life	si, nmf	39
benzo(a)pyrene	28% in 16 mo	si, nmf	41
	220-530d	si, nmf	39
alpha-BHC	0% in 7d	scf, sdw	38
beta-BHC	0% in 7d	scf, sdw	38
delta-BHC	0% in 7d	scf, sdw	38
gamma-BHC	0% in 7d	scf, sdw	38
biphenyl	37d half life	sgw, fo	43
bis-(2)chloroethoxy)-methane	0% in 7d	scf, sdw	38
bis-(2-chloroethyl)ether	100% in 7d	scf, sdw	38
bis-(2-chloroisopropyl) ether	74% in 7d	scf, sdw	38
bis-(2-ethylhexyl)-phthalate	0% in 7d	scf, sdw	38
borneol	8.9 mgCOD/g/h	bss, as	42
bromochloromethane	100% in 7d	scf, sdw	38
bromodichlorobenzene	<4.5%/w	si, nmf	50
bromodichloromethane	>99% in 2d	cfc, bm	51
bromoform	8% in 7d	scf, sdw	38
	>99% in 2d	cfc, bm	51
4-bromodiphenyl ether	0% in 7d	scf, sdw	38
1,4-butanediol	40 mgCOD/g/h	bss, as	42

TABLE 9.9 Biodegradation and Disappearance Rates for Several Organic Chemicals^a (cont.)

<i>Organic Chemical</i>	<i>Biodegradation or Disappearance Rate</i>	<i>Medium and Inoculum</i>	<i>Reference</i>
n-butanol	84 mgCOD/g/h	bss, as	42
sec-butanol	55 mgCOD/g/h	bss, as	42
tert-butanol	30 mgCOD/g/h	bss, as	42
sec-butylbenzene	100% in 7d	bgw, nmf	52
	100% in 192h	sp, nmf	53
butylbenzoate	4d half life	sgw, fo	43
butylbenzylphthalate	100% in 7d	scf, sdw	38
camphor	37d half life	sgw, fo	43
caprolactam	16 mgCOD/g/h	bss, as	42
3-carboxy-4-hydroxy-benzenesulfonic acid	11.3 mgCOD/g/h	bss, as	42
2-carboxypyridine	100% in 8d	si, nmf	46
3-carboxypyridine	100% in 4d	si, nmf	46
4-carboxypyridine	100% in 16d	si, nmf	46
chloramphenicol	3.3 mgCOD/g/h	bss, as	42
chlordane	0% in 7d	scf, sdw	38
2-chloroaniline	16.7 mgCOD/g/h	bss, as	42
3-chloroaniline	6.2 mgCOD/g/h	bss, as	42
4-chloroaniline	5.7 mgCOD/g/h	bss, as	42
chlorobenzene	60% in 7d	scf, sdw	38
	37d half life	sgw, fo	43
	< 3.8%/w	si, nmf	50
	0.2-1.9%/w	si, nmf	54
chlorodibromomethane	18% in 7d	scf, sdw	38
4-chlorodiphenyl ether	0% in 7d	scf, sdw	38
2-chloroethyl vinyl ether	64% in 7d	scf, sdw	38
2-chloronaphthalene	100% in 7d	scf, sdw	38
2-chloro-4-nitrophenol	5.3 mgCOD/g/h	bss, as	42
2-chlorophenol	85% in 7d	scf, sdw	38
	25 mgCOD/g/h	bss, as	42
4-chlorophenol	11 mgCOD/g/h	bss, as	42
2-chloropyridine	100% in 8d	si, nmf	46
3-chloropyridine	100% in 4d	si, nmf	46
4-chloropyridine	100% in 16d	si, nmf	46
chrysene	3% in 7d	scf, sdw	38
	16% in 16 mo	si, nmf	41
m-cresol	55 mgCOD/g/h	bss, as	42
o-cresol	54 mgCOD/g/h	bss, as	42
p-cresol	55 mgCOD/g/h	bss, as	42
cresols	4d half life	sgw, fo	43
1,2-cyclohexanediol	66 mgCOD/g/h	bss, as	42
cyclohexanol	28 mgCOD/g/h	bss, as	42
cyclohexanolone	51.5 mgCOD/g/h	bss, as	42
cyclohexanone	30 mgCOD/g/h	bss, as	42
	1.1d half life	sgw, fo	43

TABLE 9.9 Biodegradation and Disappearance Rates for Several Organic Chemicals^a (cont.)

<i>Organic Chemical</i>	<i>Biodegradation or Disappearance Rate</i>	<i>Medium and Inoculum</i>	<i>Reference</i>
cyclopentanol	55 mgCOD/g/h	bss, as	42
cyclopentanone	57 mgCOD/g/h	bss, as	42
2,4-D	5000h half life	gwi, nmf	45
p,p'-DDD	0% in 7d	scf, sdw	38
p,p'-DDE	0% in 7d	scf, sdw	38
p,p'-DDT	0% in 7d	scf, sdw	38
2,4-diaminophenol	12 mgCOD/g/h	bss, as	42
2,3-diaminopyridine	27% in 64d	si, nmf	46
2,6-diaminopyridine	40% in 64d	si, nmf	46
1,2,3,4-dibenzanthracene	17% in 16 mo	si, nmf	41
dibenz(a,h)anthracene	750-940d half life	si, nmf	39
dibenzofuran	100% in 1w	si, naf	40
dibromochloromethane	>99% in 2d	cfc, bm	51
1,2-dibromoethane	99% in <1m at 6-8 ppb	swi, nmf	55
	32-70% in 110d at 15-18 ppm	swi, nmf	55
	100% in 16w	si, nmf	49
di-n-butylphthalate	100% in 7d	scf, sdw	38
2,3-dicarboxypyridine	100% in 8d	si, nmf	46
2,4-dicarboxypyridine	100% in 8d	si, nmf	46
1,2-dichlorobenzene	33% in 7d	scf, sdw	38
1,3-dichlorobenzene	59% in 7d	scf, sdw	38
1,4-dichlorobenzene	46% in 7d	scf, sdw	38
dichlorobenzenes	110d half life	sgw, fo	43
dichlorobromomethane	35% in 7d	scf, sdw	38
1,1-dichloroethane	40% in 7d	scf, sdw	38
	<1.2-<2.6%/w	si, nmf	54
1,2-dichloroethane	23% in 7d	scf, sdw	38
	>99% in 2d	cfc, bm	51
1,1-dichloroethylene	62% in 7d	scf, sdw	38
	68% in 4d	swi, nmm	56
	92% in 40w	si, nmf	49
	110d half life	swi, nmf	57
cis-1,2-dichloroethylene	49% in 7d	scf, sdw	38
	100% in 50h	swi, nmm	56
	100% in 16w	si, nmf	49
	140d half life	swi, nmf	57
trans-1,2-di- chloroethylene	54% in 7d	scf, sdw	38
	100% in 50h	swi, nmm	56
	92% in 40w	si, nmf	49
	139d half life	swi, nmf	57
2,4-dichlorophenol	100% in 7d	scf, sdw	38
	1.05 mgCOD/g/h	bss, as	42
1,2-dichloropropane	39% in 7d	scf, sdw	38

TABLE 9.9 Biodegradation and Disappearance Rates for Several Organic Chemicals^a (cont.)

<i>Organic Chemical</i>	<i>Biodegradation or Disappearance Rate</i>	<i>Medium and Inoculum</i>	<i>Reference</i>
1,3-dichloropropylene	55% in 7d	scf, sdw	38
2,3-dichloropyridine	100% in 16d	si, nmf	46
2,6-dichloropyridine	100% in 8d	si, nmf	46
dieldrin	0% in 7d	scf, sdw	38
diethanolamine	19.5 mgCOD/g/h	bss, as	42
1,3-diethylbenzene	100% in 9d	bgw, nmf	52
	100% in 192h	sp, nmf	53
diethylene glycol	13.7 mgCOD/g/h	bss, as	42
diethylphthalate	100% in 7d	scf, sdw	38
1,2-dihydroxybenzene	55.5 mgCOD/g/h	bss, as	42
1,3-dihydroxybenzene	57.5 mgCOD/g/h	bss, as	42
2,5-dihydroxybenzoic acid	80 mgCOD/g/h	bss, as	42
2,3-dihydroxypyridine	100% in 64d	si, nmf	46
2,4-dihydroxypyridine	100% in 64d	si, nmf	46
2,3-dimethylaniline	12.7 mgCOD/g/h	bss, as	42
2,5-dimethylaniline	3.6 mgCOD/g/h	bss, as	42
3,4-dimethylaniline	30 mgCOD/g/h	bss, as	42
1,3-dimethyl-5-tert-butylbenzene	100% in 10d	bgw, nmf	52
	100% in 192h	sp, nmf	53
dimethylcyclohexanol	21.6 mgCOD/g/h	bss, as	42
1,2-dimethyl-3-ethylbenzene	100% in 12d	bgw, nmf	52
	100% in 192h	sp, nmf	53
1,2-dimethyl-4-ethylbenzene	100% in 11d	bgw, nmf	52
	100% in 192h	sp, nmf	53
1,3-dimethyl-2-ethylbenzene	100% in 9d	bgw, nmf	52
	100% in 192h	sp, nmf	53
1,3-dimethyl-4-ethylbenzene	100% in 11d	bgw, nmf	52
1,4-dimethyl-2-ethylbenzene	100% in 7d	bgw, nmf	52
	100% in 192h	sp, nmf	53
1,4-dimethylnaphthalene	100% in 9d	bgw, nmf	52
	100% in 192h	sp, nmf	53
2,3-dimethylnaphthalene	100% in 9d	bgw, nmf	52
	100% in 192h	sp, nmf	53
2,3-dimethylphenol	35 mgCOD/g/h	bss, as	42
2,4-dimethylphenol	100% in 7d	scf, sdw	38
	28.2 mgCOD/g/h	bss, as	42
2,5-dimethylphenol	10.6 mgCOD/g/h	bss, as	42
2,6-dimethylphenol	9.0 mgCOD/g/h	bss, as	42

TABLE 9.9 Biodegradation and Disappearance Rates for Several Organic Chemicals^a (cont.)

<i>Organic Chemical</i>	<i>Biodegradation or Disappearance Rate</i>	<i>Medium and Inoculum</i>	<i>Reference</i>
3,4-dimethylphenol	13.4 mgCOD/g/h	bss, as	42
3,5-dimethylphenol	11.1 mgCOD/g/h	bss, as	42
dimethylphthalate	100% in 7d	scf, sdw	38
2,4-dimethylpyridine	100% in 32d	si, nmf	46
2,6-dimethylpyridine	100% in 32d	si, nmf	46
2,4-dinitrophenol	64% in 7d	scf, sdw	38
	6.0 mgCOD/g/h	bss, as	42
2,4-dinitrotoluene	64% in 7d	scf, sdw	38
2,6-dinitrotoluene	70% in 7d	scf, sdw	38
di-n-octylphthalate	0% in 7d	scf, sdw	38
diphenylether	11d half life	sgw, fo	43
1,2-diphenylhydrazine	76% in 7d	scf, sdw	38
docosane	4.5-50.6% in 4w	si, nmf	58
dotriacontane	0.6-43.3% in 4w	si, nmf	58
alpha-endosulfan	0% in 7d	scf, sdw	38
beta-endosulfan	0% in 7d	scf, sdw	38
endosulfan sulfate	0% in 7d	scf, sdw	38
endrin	0% in 7d	scf, sdw	38
ethylbenzene	85% in 7d	scf, sdw	38
	100% in 12d	bgw, nmf	52
	37d half life	sgw, fo	43
	> 99% in 120w	si, nmf	49
	100% in 192h	sp, nmf	53
ethylene diamine	9.8 mgCOD/g/h	bss, as	42
ethylene glycol	41.7 mgCOD/g/h	bss, as	42
2-ethyltoluene	100% in 12d	bgw, nmf	62
3-ethyltoluene	100% in 10d	bgw, nmf	52
4-ethyltoluene	100% in 7d	bgw, nmf	52
fluoranthene	0% in 7d	scf, sdw	38
	140-440d half life	si, nmf	39
fluorene	74% in 7d	scf, sdw	38
	32-60d half life	si, nmf	39
	92%/w	si, naf	40
furfuryl alcohol	41 mgCOD/g/h	bss, as	42
furfurylaldehyde	37 mgCOD/g/h	bss, as	42
glucose	180 mgCOD/g/h	bss, as	42
	4.6-25.6h aerobic half life	si, nmf	44
	1.2-19h anaerobic half life	si, nmf	44
glycerol	85 mgCOD/g/h	bss, as	42
heptachlor	0% in 7d	scf, sdw	38
heptachlor epoxide	0% in 7d	scf, sdw	38
hexachlorobenzene	39% in 7d	scf, sdw	38

TABLE 9.9 Biodegradation and Disappearance Rates for Several Organic Chemicals^a (cont.)

<i>Organic Chemical</i>	<i>Biodegradation or Disappearance Rate</i>	<i>Medium and Inoculum</i>	<i>Reference</i>
hexachloro-1,3-butadiene	100% in 7d	scf, sdw	38
hexachloro-cyclopentadiene	100% in 7d	scf, sdw	38
hexachloroethane	100% in 7d	scf, sdw	38
hydroquinone	54.2 mgCOD/g/h	bss, as	42
2-hydroxybenzoic acid	95 mgCOD/g/h	bss, as	42
4-hydroxybenzoic acid	100 mgCOD/g/h	bss, as	42
2-hydroxypyridine	100% in 64d	si, nmf	46
3-hydroxypyridine	100% in 32d	si, nmf	46
4-hydroxypyridine	100% in 32d	si, nmf	46
indan	100% in 11d	bgw, nmf	52
	1y half life	sgw, fo	43
	100% in 192h	sp, nmf	53
ideno(1,2,3-c,d)pyrene	600-730d half life	si, nmf	39
isophorone	100% in 7d	scf, sdw	38
isophthalic acid	76 mgCOD/g/h	bss, as	42
isopropanol	52 mgCOD/g/h	bss, as	42
isopropylbenzene	100% in 11d	bgw, nmf	42
	100% in 192h	sp, nmf	53
menthol	17.7 mgCOD/g/h	bss, as	42
4-(methylamino)-phenol sulfate	0.8 mgCOD/g/h	bss, as	42
3-methyl-4-chlorophenol	77% in 7d	scf, sdw	38
methylcresols	110d half life	sgw, fo	43
4-methylcyclohexanol	40 mgCOD/g/h	bss, as	42
4-methylcyclohexanone	61.5 mgCOD/g/h	bss, as	42
methylene chloride	100% in 7d	scf, sdw	38
1-methyl-2-ethylbenzene	100% in 192h	sp, nmf	53
1-methyl-3-ethylbenzene	100% in 192h	sp, nmf	53
1-methyl-4-ethylbenzene	100% in 192h	sp, nmf	53
5-methyl-2-isopropyl-1-phenol	15.6 mgCOD/g/h	bss, as	42
1-methylnaphthalene	100% in 9d	bgw, nmf	52
	100% in 1w	si, naf	40
2-methylnaphthalene	100% in 9d	bgw, nmf	52
	100% in 1w	si, naf	40
	100% in 192h	sp, nmf	53
methylparathion	410.1h aerobic half life	si, nmf	44
2-methylpyridine	100% in 16d	si, nmf	46
3-methylpyridine	100% in 32d	si, nmf	46
4-methylpyridine	100% in 32d	si, nmf	46
naphthalene	100% in 7d	scf, sdw	38
	100% in 9d	bgw, nmf	52

TABLE 9.9 Biodegradation and Disappearance Rates for Several Organic Chemicals^a (cont.)

<i>Organic Chemical</i>	<i>Biodegradation or Disappearance Rate</i>	<i>Medium and Inoculum</i>	<i>Reference</i>
naphthalene (contd)	110d half life	sgw, fo	43
	100% in 1w	si, naf	40
	100% in 192h	sp, nmf	53
1-naphthalene-sulfonic acid	18 mgCOD/g/h	bss, as	42
naphthoic acid	15.5 mgCOD/g/h	bss, as	42
1-naphthol	38.4 mgCOD/g/h	bss, as	42
2-naphthol	39.2 mgCOD/g/h	bss, as	42
1-naphthol-2-sulfonic acid	18 mgCOD/g/h	bss, as	42
1-naphthylamine	0 mgCOD/g/h	bss, as	42
1-naphthylamine-6-sulphonic acid	0 mgCOD/g/h	bss, as	42
nitrilotriacetate	86.6-161.2 aerobic half life	si, nmf	44
	49.4-125.8h anaerobic half life	si, nmf	44
	31h half life	gwi, nmf	45
4-nitroacetophenone	5.3 mgCOD/g/h	bss, as	42
2-nitrobenzaldehyde	13.8 mgCOD/g/h	bss, as	42
3-nitrobenzaldehyde	10.0 mgCOD/g/h	bss, as	42
4-nitrobenzaldehyde	13.8 mgCOD/g/h	bss, as	42
nitrobenzene	94% in 7d	scf, sdw	38
	14.0 mgCOD/g/h	bss, as	42
2-nitrobenzoic acid	20 mgCOD/g/h	bss, as	42
3-nitrobenzoic acid	7.0 mgCOD/g/h	bss, as	42
4-nitrobenzoic acid	19.7 mgCOD/g/h	bss, as	42
2-nitrophenol	100% in 7d	scf, sdw	38
	14.0 mgCOD/g/h	bss, as	42
3-nitrophenol	17.5 mgCOD/g/h	bss, as	42
4-nitrophenol	100% in 7d	scf, sdw	38
	17.5 mgCOD/g/h	bss, as	42
N-nitroso-di-N-propylamine	14% in 7d	scf, sdw	38
N-nitrosodiphenylamine	67% in 7d	scf, sdw	38
2-nitrotoluene	32.5 mgCOD/g/h	bss, as	42
3-nitrotoluene	21.0 mgCOD/g/h	bss, as	42
4-nitrotoluene	32.5 mgCOD/g/h	bss, as	42
nonadecane	7.5-54% in 4w	si, nmf	58
octacosane	1.3-39.1% in 4w	si, nmf	58
octadecane	19.5-31.9% in 4w	si, nmf	58
1-octadecene	16.4-32.3% in 4w	si, nmf	58
octadecenoic acid	82-312.2h aerobic half life	si, nmf	44

TABLE 9.9 Biodegradation and Disappearance Rates for Several Organic Chemicals^a (cont.)

<i>Organic Chemical</i>	<i>Biodegradation or Disappearance Rate</i>	<i>Medium and Inoculum</i>	<i>Reference</i>
pentachlorophenol	18% in 7d	scf, sdw	38
perylene	0% in 16 mo	si, nmf	41
phenanthrene	100% in 7d	scf, sdw	38
	100% in 4 mo	si, nmf	41
	< 60-200d half life	si, nmf	39
phenol	97% in 7d	scf, sdw	38
	98.5 mgCOD/g/h	bss, as	42
phenylisocyanate	37d half life	sgw, fo	43
phthalic acid	78.4 mgCOD/g/h	bss, as	42
phthalimide	20.8 mgCOD/g/h	bss, as	42
n-propanol	71 mgCOD/g/h	bss, as	42
propylbenzene	100% in 11d	bgw, nmf	52
	100% in 192h	sp, nmf	53
pyrene	41% in 7d	scf, sdw	38
	97% in 16 mo	si, nmf	41
	210-1900d half life	si, nmf	39
pyridine	100% in 8d	si, nmf	46
sodium acetate	8.6h aerobic half life	si, nmf	44
	1.4-15.6h anaerobic half life	si, nmf	44
styrene	2.3-12.0%/w	si, nmf	54
sulphanilic acid	4.0 mgCOD/g/h	bss, as	42
1,1,2,2-tetra- chloroethane	0% in 7d	scf, sdw	38
	97% in 2d	cfc, bm	51
tetrachloroethylene	38% in 7d	scf, sdw	38
	0% in 190h	swi, nmm	56
	300d half life	sgw, fo	59
	87-99.98% in 2-4d	cfc, nmm	60
	86% in 2d	cfc, bm	51
	68% in 21d	swi, nmf	61
	0.9-1.8%/w	si, nmf	54
tetrachloromethane	84% in 7d	scf, sdw	38
	> 99% in 2d	cfc, bm	51
tetrahydrofurfuryl alcohol	40 mgCOD/g/h	bss, as	42
1,2,3,4-tetra- hydronaphthalene	100% in 9d	bgw, nmf	52
	100% in 192h	sp, nmf	53
1,2,3,4-tetra- methylbenzene	100% in 11d	bgw, nmf	52
	100% in 192h	sp, nmf	53
1,2,3,5-tetra- methylbenzene	100% in 9d	bgw, nmf	52

TABLE 9.9 Biodegradation and Disappearance Rates for Several Organic Chemicals^a (cont.)

<i>Organic Chemical</i>	<i>Biodegradation or Disappearance Rate</i>	<i>Medium and Inoculum</i>	<i>Reference</i>
1,2,4,5-tetra- methylbenzene	100% in 10d	bgw, nmf	52
	100% in 192h	sp, nmf	53
toluene	100% in 7d	scf, sdw	38
	100% in 10d	bgw, nmf	52
	37d half life	sgw, fo	43
	39d half life	sgw, fo	47
	37d half life	gwi, nmf	47
	100% in 30-80d	si, nmf	48
	100% in 80d	sgw, fo	48
	> 99% in 120w	si, nmf	49
	> 93%/w	si, nmf	50
	0.9-3.2%/w	si, nmf	54
	100% in 192h	sp, nmf	53
p-toluenesulphonic acid	8.4 mgCOD/g/h	bss, as	42
1,2,4-trichlorobenzene	48% in 7d	scf, sdw	38
trichlorobenzenes	11d half life	sgw, fo	43
1,1,1-trichloroethane	26% in 7d	scf, sdw	38
	300d half life	sgw, fo	59
	98% in 2d	cfc, bm	51
	< 1.1- < 3.2%/w	si, nmf	54
1,1,2-trichloroethane	3% in 7d	scf, sdw	38
trichloroethylene	51% in 7d	scf, sdw	38
	69% in 4d	swi, nmm	56
	300d half life	sgw, fo	59
	< 3.5%/w	si, nmf	50
	89% in 40w	si, nmf	49
	< 1.2- < 2.3%/w	si, nmf	54
trichlorofluoromethane	49% in 7d	scf, sdw	38
trichloromethane	48% in 7d	scf, sdw	38
	68% in 27d	swi, nmf	62
	96% in 2d	cfc, bm	51
	3% in 5d	si, nmf	63
	< 1.0- < 2.8%/w	si, nmf	54
2,4,6-trichlorophenol	100% in 7d	scf, sdw	38
triethylene glycol	27.5 mgCOD/g/h	bss, as	42
1,3,5-trihydroxybenzene	22.1 mgCOD/g/h	bss, as	42
3,4,5-trihydroxy- benzoic acid	20 mgCOD/g/h	bss, as	42
tri-isobutylphosphate	37d half life	sgw, fo	43
1,2,3-trimethylbenzene	100% in 12d	bgw, nmf	52
	100% in 192h	sp, nmf	53
1,2,4-trimethylbenzene	100% in 7d	bgw, nmf	52
	100% in 192h	sp, nmf	53
1,3,5-trimethylbenzene	100% in 12d	bgw, nmf	52
	100% in 192h	sp, nmf	53

TABLE 9.9 Biodegradation and Disappearance Rates for Several Organic Chemicals^a (cont.)

<i>Organic Chemical</i>	<i>Biodegradation or Disappearance Rate</i>	<i>Medium and Inoculum</i>	<i>Reference</i>
1,3,3-trimethyl-2-norcamphanone	110d half life	sgw, fo	43
vinyl chloride	100% in 23d	swi, nmm	56
m-xylene	100% in 7d	bgw, nmf	52
	37d half life	sgw, fo	43
	15d half life	sgw, fo	47
	29d half life	gwi, nmf	47
	100% in 65d	si, nmf	48
	100% in <300d	sgw, fo	48
o-xylene	100% in 12d	bgw, nmf	52
	11d half life	sgw, fo	43
	32d half life	sgw, fo	47
	31d half life	gwi, nmf	47
	100% in 25-60d	si, nmf	48
	100% in <300d	sgw, fo	48
	>99% in 120w	si, nmf	49
	100% in 192h	sp, nmf	53
p-xylene	100% in 7d	bgw, nmf	52
	37d half life	sgw, fo	43
	17d half life	sgw, fo	47
	100% in <300d	sgw, fo	48

^a abbreviations:

- as = activated sludge as microbial inoculum.
- bgw = batch test using groundwater.
- bm = bacterial inoculum produced in a methanogenic environment.
- bss = batch test using distilled water, dissolved salts, and the organic chemical as the sole carbon source.
- cfc = continuous-flow, fixed film laboratory study using glass bead columns.
- COD = chemical oxygen demand.
- d = day(s).
- fo = estimation based on field observation.
- gwi = groundwater incubation study.
- h = hour(s).
- mo = month(s).
- naf = natural acclimated microbial flora.
- nmf = natural microbial flora used as inoculum.
- nmm = natural microbial flora under methanogenic conditions.
- scf = static-culture flask biodegradation test, original culture.
- sdw = settled domestic wastewater utilized as microbial inoculum.
- sgw = naturally-occurring soil-groundwater system.
- si = soil incubation study.
- sm = soil microcosm study.
- sp = soil percolation study.
- swi = soil-water or sediment-water incubation study.
- w = week(s).
- y = year(s).

domonas, *Arthrobacter*, *Alcaligenes*, *Corynebacterium*, *Flavobacterium*, *Achromobacter*, *Micrococcus*, *Nocardia*, and *Mycobacterium* appear to be the most consistently isolated hydrocarbon-degrading bacteria in soil²⁷. In decreasing order *Trichoderma*, *Penicillium*, *Aspergillus*, and *Mortierella* appear to be the most consistently isolated hydrocarbon-degrading fungi in soil²⁷. In one oil in soil study, eight months after the addition of oil to soil, the number of oil-degrading bacteria in soil increased tenfold and comprised almost 50 percent of the total soil bacterial population⁶⁴. In another oil in soil study, soil receiving an application of 39.2 percent crude oil possessed the highest number of microorganisms relative to soil receiving less amounts of oil⁶⁵.

If the naturally-occurring soil microorganisms are not capable of degrading an organic chemical or waste at a sufficiently rapid rate, mutant microorganisms may work. Seeding a mutant population into a soil-groundwater system is a promising area for the biodegradation of organic chemicals other than bulk hydrocarbons. Although a number of successful case histories have been reported in the published literature, these cases lack the experimental designs needed to differentiate the effect of the mutant microorganisms from those of the naturally-occurring microorganisms. Also, no information is available regarding the relative risk to human health and the environment resulting from the presence of a mutant microorganism for an unknown, possibly indefinite, period of time in soil and groundwater.

Energy. One major factor limiting microorganism growth and metabolism in soil is the presence of a suitable and available source of energy. Soil microbiologists have long observed that wherever an available energy source is abundant in soil, microorganisms capable of utilizing that source are usually present in abundant numbers⁶⁶. A substantial fraction of the soil microorganism population is probably in a dormant state most of the time because of the inadequacy of the average soil's energy supply⁶⁶. Many industrial organic chemicals, when added to soil, stimulate soil microorganisms because they serve as energy sources.

There are many organic chemicals that are transformed by soil microorganisms which do not utilize the chemical as a carbon or energy source. The process in which an organic chemical is transformed but not utilized by an organism that derives its energy from other organic chemicals is known as cometabolism.

When cometabolism is affecting the transformation of an organic chemical, several distinct soil microorganisms are usually needed in order to substantially degrade the chemical. One organism causes an initial modification via the cometabolic process such that the second and subsequent microorganisms can use the modified chemical as an energy source to cause succes-

sive modifications. It is important to note that cometabolism does not mineralize the organic chemical to CO_2 and H_2O ; it causes an alteration in the chemical structure to form a modified chemical.

Cometabolism has been identified as a process that influences the degradation of several organic chemicals (see Table 9.10). Although our understanding of the process is far from complete, research interest in this area is high at the present time and should lead to interesting findings in the future.

The presence of some organic chemicals can have a particularly significant stimulating effect on the microbiological degradation of some organic chemicals either through cometabolism or by another mechanism. For example, the presence of fulvic acid enhanced the biodegradation of 2(methylthio)benzothiazole in a fermentor broth containing activated sludge bacteria⁷⁰. The presence of sodium ligninsulfonate enhanced the biodegradation of various mixtures of commercial PCBs (Aroclors) in a growth medium containing PCB degrading bacteria⁷¹. The adaptation to increasing concentrations of amino acids, carbohydrates, or fatty acids enhanced the ability of the microbial community of a mesotrophic reservoir to degrade m-cresol, m-aminophenol, and p-chlorophenol⁷².

The presence of an organic chemical, which possesses a chemical structure similar to the structure of the chemical of concern, can have a stimulating effect on the microbiological degradation of the chemical of concern. For example, the addition of aniline to soil containing 0.2 to 100 ppm 3,4-dichloroaniline increased the mineralization rate of 3,4-dichloroaniline severalfold⁷³. The addition of small amounts of Aroclor 1221 to a growth medium containing *Pseudomonas sp.* 7509 enhanced the degradation of Aroclor 1254⁷¹. The addition of biphenyl to an Altamont soil enhanced the degradation of Aroclor 1242⁷⁴. The process in which the addition of one chemical stimulates the degradation of another chemical with a similar chemical structure is known as analog enrichment.

The presence of some organic chemicals in soil can have an inhibitory effect on the microbiological degradation of some organic chemicals. For example, the adaptation to increasing concentrations of humic acids reduced the ability of the microbial community of a mesotrophic reservoir to degrade m-cresol, m-aminophenol, and p-chlorophenol⁷⁵. The degradation of benzene and naphthalene by a mixed microbial community from an oil refinery settling pond was inhibited until phenol was degraded⁷⁶. The mineralization of 2 ppb phenol by *Pseudomonas acidovorans* was delayed 16 hours by the presence of 70 ppb acetate, and the delay was lengthened by increasing acetate concentrations⁷⁷. When *Pseudomonas sp.* strain ANL was grown in a salts solution supplemented with 300 ppb each of glucose and aniline, glucose was mineralized first, and aniline was mineralized only after much of the glucose was converted to carbon dioxide⁷⁷.

TABLE 9.10 Organic Chemicals Modified by Cometabolism.

acenaphthalene
alkyl benzene sulfonate
anthracene
benzene
bis(4-chlorophenyl) acetic acid
butane
1-butene
cis-2-butene
trans-2-butene
n-butylbenzene
n-butylcyclohexane
carbon monoxide
3-chlorobenzoate
4-chlorotoluene
cumene
cyclohexane
cycloparaffins
p-cymene
DDT
n-decane
1,2-diethylbenzene
diethyl ether
9,10-dimethylanthracene
1,3-dimethylnaphthalene
2,3-dimethylnaphthalene
1,6-dimethylnaphthalene
2,6-dimethylnaphthalene
2,7-dimethylnaphthalene
dodecane
ethane
ethene
ethylbenzene
heptadecane
hexadecane
4-isopropyltoluene
limonene
2-methylanthracene
2-methylnaphthalene
3-methylphenanthrene
naphthalene
octadecane
pentadecane
phenylcyclohexane
propane
propene
n-propylbenzene
retene

TABLE 9.10 Organic Chemicals Modified by Cometabolism. (cont.)

tetradecane
 thianaphthene
 toluene
 2,4,5-trichlorophenoxyacetate
 tridecane
 1,2,4-trimethylbenzene
 undecane
 m-xylene
 p-xylene

Compiled from data in references 67, 68 & 69.

All the mechanisms by which organic chemicals retard the biodegradation of other organic chemicals are not known. However, one mechanism that has received little attention is diauxie or sparing⁷⁶; diauxie is an antagonistic interaction of organic chemicals in which microorganisms preferentially degrade one chemical in a mixture before synthesizing the enzymes needed to degrade other chemicals in the mixture. Microbiologists have extensively studied the preferential metabolism of sugars but not of environmentally significant organic chemicals.

Acidity and Alkalinity. The majority of soil microorganisms will thrive best in the pH range of 6 to 8. Most will tolerate well a pH range of about 4 to 9. Strong acid or alkaline conditions will inhibit the growth and metabolism of most soil microorganisms.

Not all soil microorganisms or metabolic processes should be expected to respond equally to acidity or alkalinity. For example, ammonification was relatively insensitive to acidity in a perfusion study in which soil was exposed to pH 2.0 simulated acid rain⁷⁸. In the same study, nitrification was more sensitive, being retarded in $\text{NH}_4\text{-N}$ supplemented soils exposed to pH 3.0 simulated acid rain and inhibited at pH 2.5⁷⁸. Acid rain at pH 3.7 and 3.0 did not significantly alter soil respiration but did significantly reduce nitrification⁷⁹; in another study, however, acidification had little effect on soil respiration (COD_2 evolution) until the pH was lowered below three⁸⁰. In this same study, glucose was not degraded at approximately pH 2, but was degraded after soil pH was raised to about pH 4.1 - 4.3. Nitrogen fixation in soil cores was not significantly altered by 690 days of exposure to acid rain⁸¹.

The effect of acid rain on enzymatic activities depends on the enzyme type. Protease activity was not significantly altered in any of five soils in 97 or

690 day experiments in which pH 3.7 and 3.0 acid rain was percolated through soil columns⁸¹. In the same study, dehydrogenase and phosphatase activities decreased in soils exposed to acid rain for 690 days.

Temperature. Microbiological reactions follow the general rule that the rate of a chemical's reaction increases as the temperature increases³⁴. As a result, warmer temperatures favor relatively faster biodegradation rates.

Temperature limits to microorganism activity do exist. Because microorganisms require liquid water, the lower temperature limit to microorganism activity is the freezing point of water³⁴. A number of researchers have reported the degradation of hydrocarbons at or slightly above the freezing point of water⁸². Because most microorganisms contain essential enzymes that are denatured at or above 50° Celsius, the higher temperature limit to microorganism activity is about 50° Celsius³⁴. Groundwater temperatures in the U.S.A. fall within these limits (see Figure 9.3).

Moisture. Soil microorganisms need water to support their metabolic processes. As a result, microorganisms are expected to respond to changes in soil moisture content through a complex series of interactions involving nutrient fluxes, soil temperature, pore size changes, and soil atmosphere changes.

An interesting series of published experiments gives good information on how soil microorganisms respond to changes in soil moisture content. In field plots receiving rainfall, the number of bacteria doubled within three days⁸⁴; however, during a period of drought immediately following the rainfall period, the number of bacteria decreased by about 30 percent, then increased again as rainfall commenced. In field plots receiving irrigation, the number of bacteria increased by 50 percent and then remained constant⁸⁴. The change in microbial activity due to a change in soil moisture content may be substantial under some circumstances; for example, rewetting a dry soil caused as much as a 40X increase in soil respiration⁸⁵.

In general, extreme moisture conditions should be unfavorable for microorganism growth and metabolism in unsaturated zone soil. Because individual species are seldom eliminated entirely in extremely wet or dry soil moisture conditions, the drying of a wet soil or the rewetting of a very dry soil should reestablish microorganism activity. Between these extreme conditions, soil moisture content should have an undramatic effect on the microbiological degradation of organic chemicals, as evidenced by experiments on the land treatment of a refinery and a petrochemical sludge⁸⁶.

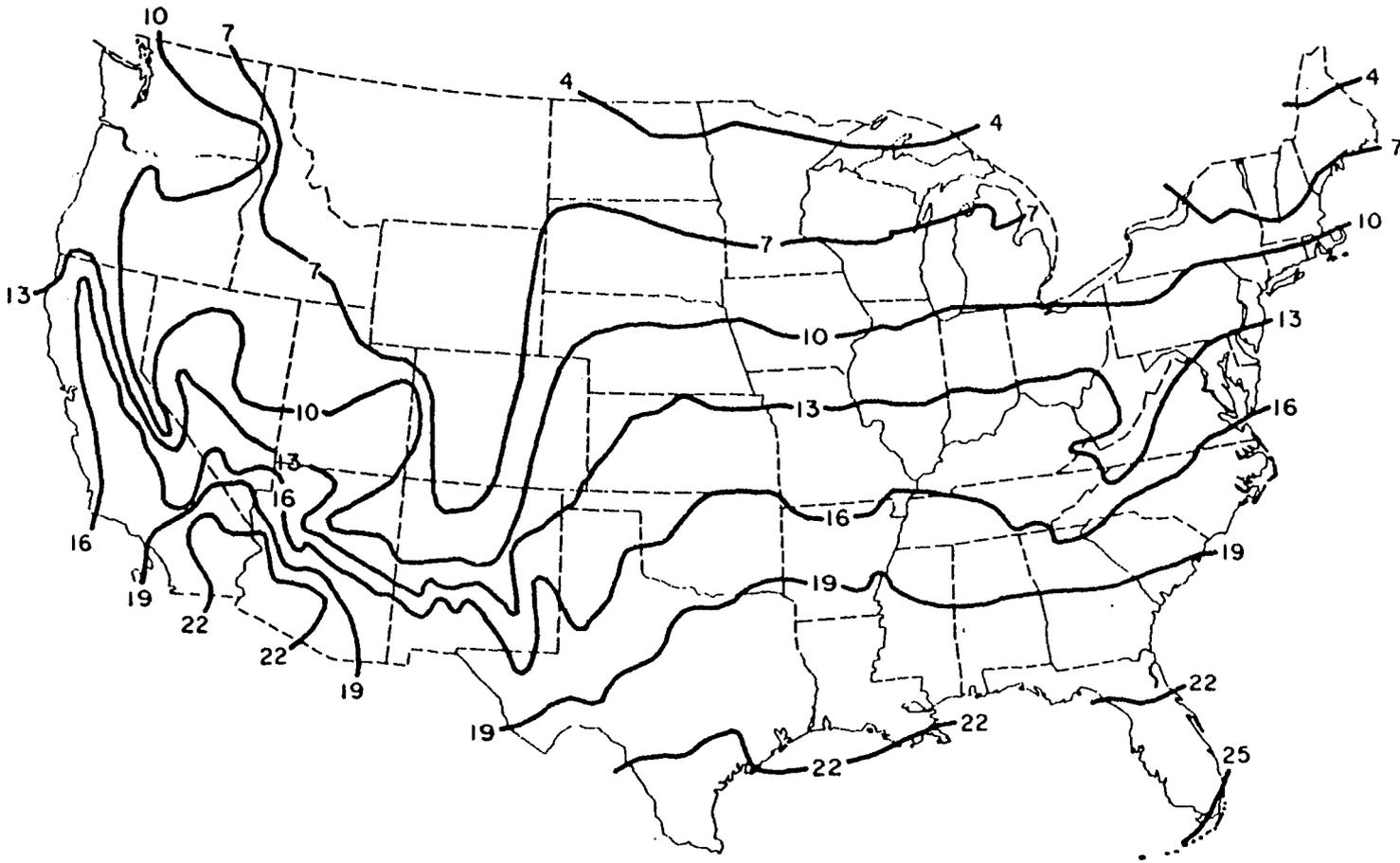


FIGURE 9.3 Approximate temperature of groundwater, in degrees Celsius, in the continental United States at depths of 10 to 25 meters.⁸³

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Essential Elements. Research has shown that certain elements are necessary for the normal growth and nutrition of biota, including microorganisms. These essential elements include: nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, iron, manganese, copper, zinc, boron, molybdenum, chlorine, and cobalt.

It is most important to recognize that microorganism growth and metabolism is dependent upon all of these elements, and that any one of them, if out of balance, can reduce or entirely prevent growth or metabolism. These elements must be present and available to the microorganism in (a) a usable form, (b) appropriate concentrations, and (c) proper ratios.

Under normal circumstances, soil is the provider of essential elements to microorganisms. However, when an organic chemical enters a soil system in bulk quantities, the soil's supply of elements is almost always inadequate to support desirable biodegradation rates. The addition of these elements usually results in accelerated biodegradation rates.

When a soil receives a relatively large amount of an essential or nonessential element, several events may occur. First, an initial reduction in the number of soil microorganisms may occur. Second, the number of species of soil microorganisms may decrease. Third, soil processes performed by soil microorganisms may be adversely affected. Fourth, element-resistant microorganisms may adapt to the soil and its relatively high elemental concentration.

Table 9.11 lists information on microorganism processes affected by metals in soil. An analysis of the information in Table 9.11 revealed several important facts regarding the effect of metals on soil microorganism processes. First, a concentration of a metal may adversely affect one process, yet have no effect on another. For example, 1000 ppm Cd in a pH 4.8 sandy loam soil retards nitrification but has no effect on ammonification.

Second, the soil type can have a very significant effect on how metals affect microorganism processes. For example, 100 ppm Pb in a pH 5 loamy sand caused a 25 percent decrease in respiration. However 1000 ppm Pb in a pH 5 sandy loam soil had no effect on respiration. Because sandy loam soil should have a larger surface area relative to loamy sand soil, the sandy loam soil probably fixed more Pb than the loamy sand soil. Fixed Pb is not available to microorganisms. In summary, it is not sufficient to know just the total metal concentration when assessing the effect of metals on soil microorganisms; the fixation reactions discussed in Chapter 3 will significantly influence the effect of metals on soil microorganisms; the fixation reactions discussed in Chapter 3 will significantly influence the effect of metals on soil microorganisms.

Third, soil pH can have a very significant effect on how metals affect microorganism processes. For example, 1000 ppm Zn had no effect on nitrification and N mineralization at pH 6.0, a slight effect at pH 7.0, and sig-

nificantly retarded these two processes at pH 7.7. Because pH affects the solubility of Zn, changes in pH should change the amount of fixed Zn, which changes the amount of Zn available to the microorganism.

Fourth, the presence of other bulk organic materials in soil can have a very significant effect on how metals affect microorganism processes. For example, 10,000 ppm Pb in a pH 5 sandy loam soil retards respiration. However, 15,000 ppm Pb plus two percent humic acid in a pH 5 sandy loam soil had no effect on soil respiration. In addition, 20,000 ppm Pb plus four percent compost in a pH 5 sandy loam soil had no effect on soil respiration after 20 days of incubation.

Fifth, in neutral pH soils, relatively large amounts of metals must be present in soils to have an adverse impact on microorganism processes. On the other hand, in acidic soils, relatively small amounts of metals have an adverse impact on microorganism processes.

Some microorganisms have adapted mechanisms to maintain low intracellular concentrations of metals while surviving in soils with relatively high metal concentrations⁹². An understanding of the biochemical basis for microorganism resistance to metal toxicity is still emerging. Several mechanisms have been identified. Some microorganisms have energy-driven efflux pumps that keep intracellular concentrations of metals low by pumping the metal out of its cell. Some microorganisms can convert enzymatically and intracellularly a more toxic form of an element or metal into a less toxic form. Some microorganisms can synthesize intracellular polymers that trap and remove metals from the intracellular solution. Some microorganisms can bind large amounts of metal ions to their cell surfaces via precipitation or by covalent or ionic bonding. Also, some microorganisms can biomethylate metals; the methylated species can then be transported out of the microorganism by diffusion-controlled processes.

Organic Chemical Concentration. The concentration of an organic chemical in a soil system affects its biodegradation rate. For some chemicals, the biodegradation rate is limited by low concentrations; for others, the rate is limited by high concentrations. At the present time, published scientific studies can only be utilized to derive generalizations on the effect of organic chemical concentration on biodegradability.

Low concentrations of an organic chemical can affect its degradation rate in several ways. First, the lower concentration may become a limiting factor because it may not induce the enzymes responsible for degradation. Second, the lower concentration may result in a prolonged acclimation period. Third, the low concentration may prohibit the chemical from serving as an energy source for microorganism metabolism.

Many biodegradation studies have been performed while utilizing chemi-

TABLE 9.11 Effect of Various Metals on Microorganisms.

<i>Metal</i>	<i>Soil Type</i>	<i>Soil Concentration</i>	<i>Microbial Process</i>	<i>Effect</i>	<i>Ref.</i>
Ag	loamy sand, pH 5	10 ppm	Respiration	43% Decr	87
	loamy sand, pH 5	100 ppm	Respiration	72% Decr	87
Bi	loamy sand, pH 5	10 ppm	Respiration	11% Decr	87
	loamy sand, pH 5	100 ppm	Respiration	4% Decr	87
Cd	loamy sand, pH 5	10 ppm	Respiration	17% Decr	87
	loamy sand, pH 5	100 ppm	Respiration	11% Decr	87
	silt loam, pH 6.75	100 ppm	Denitrification	Signif. Retard.	88
	sandy loam, pH 4.8	500 ppm	Nitrification	Retard.	89
	sandy loam, pH 4.8	1000 ppm	Ammonification	None	89
	sandy loam, pH 4.8	1000 ppm	Nitrification	Retard.	89
Co	loamy sand, pH 5	10 ppm	Respiration	4% Decr	87
	loamy sand, pH 5	100 ppm	Respiration	23% Decr	87
Cu	loamy sand, pH 5	10 ppm	Respiration	3% Decr	87
	loamy sand, pH 5	100 ppm	Respiration	25% Decr	87
	silt loam, pH 6.75	250 ppm	Denitrification	Retard.	88
Hg	loamy sand, pH 5	10 ppm	Respiration	33% Decr	87
	loamy sand, pH 5	100 ppm	Respiration	55% Decr	87
Ni	loamy sand, pH 5	10 ppm	Respiration	6% Decr	87
	loamy sand, pH 5	100 ppm	Respiration	28% Decr	87

TABLE 9.11 Effect of Various Metals on Microorganisms. (cont.)

<i>Metal</i>	<i>Soil Type</i>	<i>Soil Concentration</i>	<i>Microbial Process</i>	<i>Effect</i>	<i>Ref.</i>
Pb	loamy sand, pH 5	10 ppm	Respiration	6% Decr	87
	loamy sand, pH 5	100 ppm	Respiration	25% Decr	87
	sandy loam, pH 5	1000 ppm	Respiration	None	90
	silt loam, pH 6.75	1000 ppm	Denitrification	Retard.	88
	sandy loam, pH 5	10,000 ppm	Respiration	Retard.	90
	sandy loam, pH 5	15,000 ppm + 2% humic acid	Respiration	None	90
	sandy loam, pH 5	20,000 ppm + 4% compost	Respiration	Initial retard; none after 20 days	90
Sb	loamy sand, pH 5	10 ppm	Respiration	18% Decr	87
	loamy sand, pH 5	100 ppm	Respiration	31% Decr	87
Sn	loamy sand, pH 5	10 ppm	Respiration	16% Decr	87
	loamy sand, pH 5	100 ppm	Respiration	35% Decr	87
Ti	loamy sand, pH 5	10 ppm	Respiration	4% Decr	87
	loamy sand, pH 5	100 ppm	Respiration	28% Decr	87
Zn	loamy sand, pH 5	10 ppm	Respiration	21% Decr	87
	loamy sand, pH 5	100 ppm	Respiration	45% Decr	87
	silt loam, pH 6.75	250 ppm	Denitrification	Retard.	88
	—	1000 ppm	Nitrification	None at pH 6.0 Slight at pH 7.0 Retard. at pH 7.7	91
	—	1000 ppm	N mineralization	None at pH 6.0 Slight at pH 7.0 Retard. at pH 7.7	91

^a Abbreviations:

Decr. = decrease
Retard. = retardation
Signif. = significant

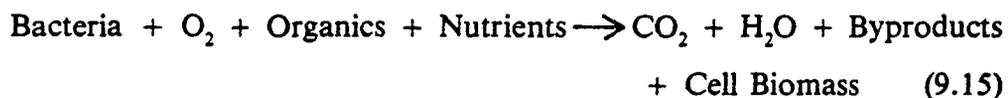
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cal concentrations that are higher than those encountered in the field. Many researchers have assumed that if a chemical is readily biodegradable at a moderate or high concentration, then ppb or ppt concentrations of the same chemical should also be readily biodegradable. Because this assumption does not hold for many chemicals, one should always check published studies to determine the concentration range studied during a particular biodegradation test, especially if one is interested in biodegradation at relatively low concentrations. Also, it is important to remember that studies utilizing very low concentrations may result in a reaction rate so slow that the chemical was reported as nondegrading, when in fact it was degrading.

All microorganisms are not affected to the same extent by a chemical or its metabolite at a certain concentration. The data on the effects of DDT on selected species of soil microorganisms listed in Tables 9.12 and 9.13 exemplify this effect. An organic chemical at a given concentration (a) may be lethal to one specie, (b) may serve as an energy source for another specie with metabolic stimulation being the end result, (c) may be degraded by another specie as a cometabolite, or (d) may have no significant metabolic effect in yet another specie.

In general, relatively large concentrations of an organic chemical are usually needed in order to significantly affect all microorganisms in a soil. For example, an analysis of the data presented in Table 9.13 will reveal that very large concentrations of DDT, greater than 20,000 ppm in soil, may be needed in order to adversely affect all four of the most important soil microbial processes. It is important to note that rarely is DDT present as a sole pesticide in soil on viable agricultural and horticultural farms; therefore, the soil loading rates listed in Tables 9.12 and 9.13 only reflect DDT concentrations and not the concentrations of DDT metabolites or other pesticides which were present.

Oxygen and the Redox Potential. The degradation of organic chemicals can occur under aerobic or anaerobic conditions, i.e., with or without oxygen. Under aerobic oxidation, molecular oxygen serves as an electron acceptor; one atom of an oxygen molecule is incorporated into the structure of the organic chemical, while the second combines with hydrogen to form water. The general process can be described by the following equation:



Approximately 5 to 50 percent of the organic material metabolized will be transformed into cell biomass. The more refractive a compound, the less carbon there is available for cell growth. Therefore, an increase in cell number

TABLE 9.12 The Effects of DDT on Selected Species of Microorganisms.

<i>Organism</i>	<i>DDT Concentration (ppm)</i>	<i>Effect</i>
Bacteroides fragilis	0.01	Inhibition
Fusarium oxysporum	0.1	Inhibition
Heliscus submersus	0.1-60	Stimulation
Nitrifying bacteria	0.5-10.0	No Effect
Mycorrhiza	< 1.0	Stimulation
Mycorrhiza	1.0-10.0	Inhibition
Aquatic hyphomycetes	> 2.0	Stimulation
Phycomycetes	2.0-60	Stimulation
Hyphomycetes	2.0-60	Stimulation
Nitrogen fixing bacteria	5.0-500	No Effect
Spore forming bacteria	5.0-500	No Effect
Azotobacter	5.0-500	No Effect
Actinomycetes	5.0-500	No Effect
Nitrifying bacteria	1,000	Inhibition
Ammonifying bacteria	1,000	Inhibition
Sulfur oxidizing bacteria	1,000	Inhibition

Compiled from data presented in Ref. 93.

TABLE 9.13 A Summary of the Effects of DDT on Microbial Processes in Soil.

<i>Process</i>	<i>DDT Concentration (ppm)</i>	<i>Effect</i>	<i>Reference</i>
CO ₂ evolution	1.0-2,500	No Effect	93
	100	Stimulation	94
Nitrate production	25-100	Stimulation	93,94
	500-20,000	No Effect	93
Ammonification	0.5-500	No Effect	93
	1000	Inhibition	95
Nitrification	200	No Effect	96

is directly related to the biodegradability of the compound.

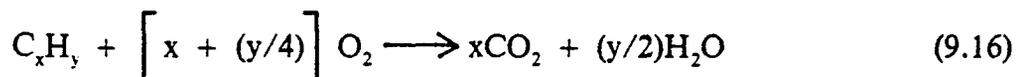
Some organic chemicals can degrade in anaerobic environments at substantially greater rates than in aerobic environments. For example, no toxaphene degradation was observed in a Crowley silt loam that was incubated aerobically in the laboratory for six weeks⁹⁷; however, extensive degradation occurred during anaerobic degradation. During anaerobic conditions, molecules other than oxygen are used as the final electron acceptor (see Table 9.14).

For many organic chemicals, anaerobic biodegradation generally proceeds

TABLE 9.14 Relationship Between Respiration, Redox Potential, and Typical Acceptors and Products⁹⁸

<i>Form of Respiration</i>	<i>Typical Redox Potential</i>	<i>Electron Acceptors</i>	<i>Proa.</i>
Aerobic respiration	+ 400 mV	O ₂	H ₂ O
Nitrate respiration & Denitrification	- 100 mV	NO ₃ ⁻	NO ₂ ⁻ , N ₂
Sulfate reduction	- 160 to - 200 mV	SO ₄ ²⁻	HS ⁻
Methanogenesis	- 300 mV	CO ₂	CH ₄

at a much lower rate than aerobic biodegradation. However, the introduction of oxygen into an anaerobic soil system can stimulate biodegradation. It is important to remember, however, that the amount of oxygen needed will depend upon the concentration of the organic chemical(s). The theoretical amount of oxygen required to degrade 1 mg/l of a hydrocarbon substrate can be calculated by performing a stoichiometric analysis for the given substance, as shown by the following equation:



Usually, about 3 to 4 mg/liter of oxygen is required to degrade 1 mg/liter of a medium-length hydrocarbon compound. If 50 percent of the organic material is converted to bacterial cell matter and the other half oxidized to carbon dioxide and water, only 4 to 6 mg/liter of organic material can be converted and oxidized under oxygen saturation conditions. Thus, for contaminated groundwaters having organic concentrations significantly higher than the above values, in-line aeration prior to injection is insufficient, because only about 10 mg/liter dissolved oxygen can be attained on a single pass, and the reinjected groundwater will use up all available oxygen in a very short period of time.

Organic chemicals present in high concentrations in groundwater are not degraded aerobically until (a) dispersion during transport decreases the chemical's concentration in groundwater, or (b) oxygen is added to the soil-groundwater system. In soils containing hydrocarbon at residual saturation, the estimated volumes of water containing sufficient dissolved oxygen to completely renovate the hydrocarbon saturated soil are enormous: 5000 volumes for stony to coarse gravelly soils, 8000 volumes for gravelly to coarse sandy soils, 15,000 volumes for coarse to medium sandy soils, 25,000 volumes for medium to fine sandy soils, and 32,000 volumes for fine sandy to silt soils⁹⁹.

Oxygen can be added to a soil-groundwater system by air sparging. The solubility of air in water is about 40 to 50 ppm; the amount of oxygen, there-

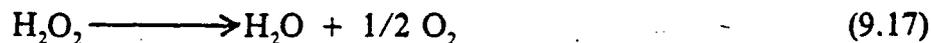
fore, that could be added to the system would be at most 8-10 ppm. This amount can be rapidly depleted by an active microorganism population¹⁰⁰, as discussed above.

Oxygen can be added to a soil-groundwater system by injecting pure oxygen into the system. Use of pure oxygen limits the available oxygen to a 40-50 ppm level¹⁰⁰. However, because the hydrostatic pressure of shallow aquifers is essentially atmospheric pressure, degassing usually occurs immediately¹⁰⁰.

Oxygen can be added to soil-groundwater systems in the form of colloidal gas apheres¹⁰¹. Colloidal gas apheres (CGAs) are a microdispersion of air or gas encapsulated in a thin film of water considerably thicker than a monolayer. CGAs are similar to soap bubbles in structure but are colloidal in size. Almost any water soluble surfactant and any gas of limited solubility can be used to produce a typical CGA dispersion of 60-70 percent air in the form of 25 to 50 micron bubbles. CGAs were first produced by passing a dilute surfactant solution through a venturi throat into which a very small gas entry port had been placed. If the velocity of the solution flowing through the venturi exceeds a critical velocity, air will be sucked into the venturi at the throat and shear off by solution passage. This ingestion of air will cause very small, very uniform bubbles to be introduced into solution; these bubbles do not coalesce when they collide, unlike air bubbles created by sparging or electrolysis that are 2 to 1000 times larger and tend to coalesce and rise rapidly to the surface.

Laboratory studies on the in situ biodegradation of hexadecane utilizing CGAs gave results revealing that CGAs were effective carriers of oxygen needed for biodegradation¹⁰¹. CGAs made with sodium dodecyl benzene sulfonate were injected into an unconsolidated saturated sand containing 200 ppm hexadecane. One series of experimental units were injected with air CGAs; another, with pure oxygen CGAs. *Pseudomonas putida* and other hexadecane degrading organisms isolated from primary sludge were inoculated into the units. Approximately 90 percent of the hexadecane was degraded in units containing oxygen CGAs and 70 percent was degraded in units containing air CGAs in 96 hrs with reaerations at 48 and 72 hrs.

The addition of hydrogen peroxide to groundwater can substantially increase oxygen levels. Because hydrogen peroxide is miscible with water, the amount of oxygen added to the system is limited only by the reactivity of hydrogen peroxide. One molecule of hydrogen peroxide can generate one-half part of oxygen:



Although hydrogen peroxide can be toxic to microorganisms, it can be added

to soil-groundwater systems at concentrations up to 100 or 200 ppm without being toxic¹⁰²; concentrations as high as 1000 ppm can be attained without toxic effects if a proper acclimation period is provided¹⁰².

It is most important to recognize that the hydrogen peroxide added to a soil system to enhance microorganisms can react with the organic chemical of concern and with naturally-occurring soil organic matter. Hydrogen peroxide is an oxidizing agent. The addition of significant amounts of hydrogen peroxide to a Canadian podzol subsurface soil and to two tropical volcanic surface soils produced many water-soluble organic compounds such as alkanes, aliphatic acids, phenols, phenolic acids, benzenecarboxylic acids, and organonitrogen and organosulfur chemicals (see Table 9.15)¹⁰³.

In addition, iron catalyzes the decomposition of hydrogen peroxide in groundwater. A standard practice to avoid decomposition by iron is to add phosphate into treated, injected water in sufficient amounts to precipitate iron. Organic inhibitors can be added to stabilize the degradation rate of hydrogen peroxide so that the oxygen demand of soil microorganisms is balanced by the oxygen from decomposing hydrogen peroxide.

Adsorption. Adsorption can either increase or decrease a microorganism's ability to degrade an organic chemical. The increase in the degradation of some adsorbed organic chemicals may be related to the distribution of the microorganism population in a soil system. There is a greater population density of microorganisms on or near soil particle surfaces than in the water phase; as a result, the adsorption of an organic chemical increases the concentration of the chemical in areas where microorganisms abound, and the potential for the microorganism to attack the chemical is enhanced.

The increase in the degradation of some adsorbed organic chemicals may be due to the influence of microbially produced surface active agents or biosurfactants. Some species of *Clostridium*, *Corynebacterium*, *Bacillus*, *Nocardia*, and *Pseudomonas* produce biosurfactants, which are broadly grouped as carbohydrate-containing, amino acid-containing, phospholipids, fatty acids, and neutral acids. These biosurfactants may aid the transport of the adsorbed organic chemical to the active enzyme site where degradation is catalyzed.

The decrease in the degradation rate of some adsorbed organic chemicals may be due to the ability of microorganisms to attack only those chemicals dissolved in the water phase. The adsorbed chemical is protected from degradation even though microorganisms are present in both solid and water phases. A general review of the published literature revealed that adsorbed organic chemicals generally tend to be less subject to degradation by soil microorganisms.

TABLE 9.15 Organic Chemicals Produced by the Addition of Hydrogen Peroxide
Three Soils^a.

1,2-benzenedicarboxylic acid dimethyl ester
1,3-benzenedicarboxylic acid dimethyl ester
1,4-benzenedicarboxylic acid dimethyl ester
benzenepentacarboxylic acid pentamethyl ester
1,2,3,4-benzenetetracarboxylic acid tetramethyl ester
1,2,3,5-benzenetetracarboxylic acid tetramethyl ester
1,2,4,5-benzenetetracarboxylic acid tetramethyl ester
1,2,3-benzenetricarboxylic acid trimethyl ester
1,2,4-benzenetricarboxylic acid trimethyl ester
bis-(2-ethylhexyl)phthalate
6-carbomethoxy-4-pyridinecarboxaldehyde
decyl methyl ester
di-isobutyl phthalate
3,4-dimethoxyacetophenone
3,4-dimethoxy-1,5-benzenedicarboxylic acid dimethyl ester
3,5-dimethoxybenzoic acid methyl ester
dioctyl adipate
docosane
docosyl methyl ester
dodecyl methyl ester
eicosyl methyl ester
ethylbenzylsulfonate
hexadecyl methyl ester
1,6-hexanedicarboxylic acid dimethyl ester
3-methoxy-1,2-benzenedicarboxylic acid dimethyl ester
2-methoxy-1,3,4,5-benzenetetracarboxylic acid tetramethyl ester
2-methoxy-1,3,5-benzenetricarboxylic acid trimethyl ester
3-methoxy-1,2,4-benzenetricarboxylic acid trimethyl ester
3-methoxybenzoic acid methyl ester
6-methylacetate-4-pyridinecarboxaldehyde
octadecyl methyl ester
1,2,3-propanetricarboxylic acid trimethyl ester
tetracosyl methyl ester
tetradecyl methyl ester

a - compiled from data presented in reference 103.